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The sensitivity of stock assessment's outcomes to the variation of Natural Mortality (M) in the Spanish Mediterranean fisheries

MOUZAI TIFOURA AMINA
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Universitat d'Alacant
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CIHEAM
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a 25 de septiembre de 2019

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Trabajo realizado en Centro Oceanográfico de Murcia del Instituto Español de Oceanografía, España, bajo la dirección de Dr. Antonio Esteban Acón

Y presentado como requisito parcial para la obtención del Diploma Master of Science en Gestión Pesquera Sostenible otorgado por la Universidad de Alicante a través de Facultad de Ciencias y el Centro Internacional de Altos Estudios Agronómicos Mediterráneos (CIHEAM) a través del Instituto Agronómico Mediterráneo de Zaragoza (IAMZ).

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San Pedro del Pinatar, a 18. de Julio .2019

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Esta Tesis fue defendida el día 18 de Julio de 2019 ante un Tribunal Formado por:

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*I would like to dedicate this thesis to my beloved “**Little and Big family**”*

Without whom none of my success would be possible.

ABSTRACT

Stock assessments involve statistical and mathematical methods to make quantitative statements about the status of harvested populations and predictions about how they are likely to respond to alternative management choices. There are often considerable uncertainties in the population parameter estimates used in the assessment models, particularly for parameters such as growth rates, Natural Mortality, Fishing Mortality patterns and spawning stock biomass and its relationships with recruitment.

Assumptions recurrently have to be made in order to facilitate the tasks for the decision-makers but also for built scientific bases for fisheries management advice.

A strong focus on natural selection factors such as natural mortality may be necessary to better understand the stock's behaviour as well as the relationship that exists with fishing mortality, so defining exploitation rates. As a result, to be able to develop a vision of a good management plan in the best estimate of the reference points which are considered as a scientific basis and necessary step for the decision-making process. This parameter is treated almost like an externally defined parameter which corresponds for the most of time to 0.2/ year.

Regarding this, the present case of study, which focus on the Spanish Mediterranean trawl fisheries, has been undertaken to describe the importance of the natural mortality rate (M) in the stock assessment process and how this could be sensitive to change of its results.

Following an argued method by the GFCM and used by the majority of the Mediterranean countries, the XSA was run with different values of M calculated with methods depending or not to age, using the FLR library, to test the sensitivity to this parameter and then describe possible changes in management advice.

Keywords: Stock assessments, Natural Mortality, Sensitive, Spanish Mediterranean trawl fisheries, XSA

RESUMEN

La evaluación de stock implica métodos estadísticos y matemáticos para hacer declaraciones cuantitativas y cualitativas sobre el estado de las poblaciones explotadas, así como pronósticos de cómo es probable que respondan a las decisiones de gestión.

Las estimaciones de los parámetros de población utilizados en los modelos de evaluación pueden presentar algunas incertidumbres, por ejemplo, las tasas de crecimiento, la mortalidad natural, los patrones de mortalidad por pesca, la biomasa del stock reproductor y su relacione con el reclutamiento.

Las suposiciones se deben hacer de forma recurrente et sencilla para facilitar el proceso de la toma de decisiones, pero también para construir bases científicas para la gestión pesquera.

De otra manera, se puede requerir un fuerte enfoque en la mortalidad natural tratado generalmente como un parámetro fijo con un valor de 0.2/año, para entender mejor el comportamiento de los recursos marinos explotados y la relación que existe con la mortalidad por pesca que define las tasas de explotación. Así, para poder desarrollar una visión de un buen plan de gestión en la mejor estimación de los puntos de referencia que se consideran una base científica necesaria para el proceso de toma de decisión.

Con respecto a esto, el presente caso de estudio, que se centra en las pesquerías de arrastre del Mediterráneo Español, se realizó para describir la importancia de la tasa de mortalidad natural en el proceso de evaluación de stock y cómo esto podría influir y cambiar el régimen decisional.

Siguiendo un método argumentado al nivel mediterráneo, la XSA se ejecutó con diferentes valores de M calculados con métodos dependientes o no de la edad, utilizando la biblioteca FLR, para probar la sensibilidad a este parámetro y luego describir posibles cambios en el asesoramiento de gestión.

Palabras clave: Evaluaciones de stocks, Mortalidad Natural, Sensibilidad, Cambio, GFCM, XSA.

RESUME

L'évaluation des stocks implique des méthodes statistiques et mathématiques permettant de formuler des déclarations quantitatives et qualitatives sur l'état des populations exploitées, aussi des prévisions sur la manière dont elles sont susceptibles de réagir à des décisions de gestion. Les modèles utilisés dans le processus d'évaluation des stocks, emploient souvent des paramètres biologiques incertaines, en particulier les paramètres de croissance, la mortalité naturelle, la mortalité par pêche, la biomasse du stock reproducteur et le recrutement.

Dans ce contexte, il est important de prendre en considération ces incertitudes afin de faciliter la tâche des décideurs, mais également de créer des bases scientifiques solides pour les avis en matière de gestion des pêcheries.

Un accent particulier sur les facteurs de sélection naturelle comme la mortalité naturelle peut-être nécessaire pour mieux comprendre le comportement des ressources marines exploitables mais aussi de définir sa relation avec la mortalité par pêche qui détermine les taux d'exploitation. Cela mène à développer une bonne vision concernant les plans de gestion avec une meilleure estimation des points de référence, considérées comme une base scientifique nécessaire et une étape primordiale pour le processus décisionnel.

Certains auteurs prévoient que la mortalité naturelle (M), traité presque comme un élément défini en externe qui correspond généralement à 0,2 / an, augmenterait avec environ la moitié de la mortalité par pêche si le stock de poisson avait eu suffisamment de temps pour atteindre un nouvel équilibre évolutif (Jørgensen & Holt, 2013).

À cet égard, le présent cas d'étude, axé sur les pêcheries chalutières du méditerranée Espagnol, a été entrepris pour décrire l'important rôle que joue la mortalité naturelle (M) dans le processus d'évaluation des stocks et indiquer comment celui-ci pourrait influencer et définir le régime décisionnel.

Suivant une méthode convenue par la CGPM et utilisée par la majorité des pays méditerranéens, la XSA a été exécuté avec des valeurs distinctes de M calculées avec différentes méthodes, dépendantes ou non de l'âge, à l'aide de la bibliothèque FLR, pour tester la sensibilité à ce paramètre et décrire ensuite les possibilités des changements dans les processus de gestion.

Mots-Clés : L'évaluation des stocks, mortalité naturelle, sensibilité, XSA.

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ACRONYMS

***ARA**: Aristeus antennatus*

BRP: Biological Reference Points

EU: European Union

F: Fishing mortality

FAO: Food and Agriculture Organization of the United Nations

FLR: Fisheries Library in R

F_{MSY}: Fishing mortality rate of maximum sustainable yield

F_{curr}: Current fishing mortality

$F_{0.1}$: Fishing mortality corresponding to a point on the yield per recruit curve where the slope is 10% of that at the origin.

GFCM: General Fisheries Commission for the Mediterranean

GSA: Geographical Subarea

ICES: International Council for the Exploration of the Sea

IEO: Instituto Espanol de Oceanografia

L2AGE4: Lenght to age program

M: Natural Mortality

MAPAMA: Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente de España

MSY: Maximum Sustainable Yield

***MUT**: Mullus barbatus*

***Overfished (or overexploited)** - A stock is considered to be overfished when its abundance is below an agreed biomass-based reference target point, like B0.1 or BMSY. To apply this denomination, it should be assumed that the current state of the stock (in biomass) arises from the application of excessive fishing pressure in previous years. This classification is independent of the current level of fishing mortality.*

***Stock subjected to overfishing (or overexploitation)** - A stock is subjected to overfishing if the fishing mortality applied to it exceeds the one it can sustainably stand, for a longer period. In other words, the current fishing mortality exceeds the fishing mortality that, if applied during a long period, under stable conditions, would lead the stock abundance to the reference point of the target abundance (either in terms of biomass or numbers)*

PRODBIOM : Program for the computation of natural mortality, developed by Abella et al., (1998)

SAC: The Scientific Advisory Committee on Fisheries

SGP: Secretaría General de Pesca

SSB: Spawning Stock Biomass

STECF: Scientific Technical and Economic Committee for Fisheries

WGSA: Working Group on Stock Assessment

WGSAD: Working Group on Stock Assessment of Demersal species

XSA: Extend Survivors Analysis

INTRODUCTION

INTRODUCTION

It's common knowledge that fishing activity is considered one of the most important practices within a strong economic plan. The enhancement and the improvement of a main regulation fisheries devices take into account the obtaining of a continuing yield with maximum economic returns but at the same time ensure the respect of different ecosystem components.

To achieve this goal, the fishery management must necessarily understand and then consider the resources' life history information, such as growth pattern, reproduction parameters and characteristics, the factors which can affect the survivorship of this resource like the different mortalities rates and finally, the harvesting strategy that presents an important parameter to be undertaken within each management plan.

The Mediterranean is amongst the most impacted regional sea areas, as a consequence of different anthropogenic pressures on different coastal and marine ecosystems within the Basin: habitat modifications and losses, climate change (e.g. global warming, acidification and sea-level rise), pollution, coastal urbanization, overexploitation/ overfishing and the intentional or indirect introduction of alien species. (Mannino et *al*., 2017). Knowing the importance and peculiarities of fisheries in this area, several management plans have been pledged.

In the fact, recognising the need for strong regional cooperation, the General Fishery Commission of the Mediterranean (GFCM) was established to promote the development, the conservation, the rational management and the best utilization of living marine resources in the region. Among its various responsibilities, the GFCM regularly reviews the state of fisheries, including the economic and social aspects of the fishing industry, as a basis for the formulation of scientific and management advice conducive to sustainable and responsible fisheries (FAO, 2018-b).

In this respect, the establishment of harvest control rules for any fishery depends on the stock assessment results of its main target species and in the same time takes into account the different reference points identified to that aim.

One of these constraints consists of the Biological reference points which provide the basis for specifying objectives for fishery management. Limit reference points define the boundaries of a situation that could cause serious harm to stock, while target reference points are used to determine harvest control rules that are risk-averse and have a low probability of causing serious harm. *Limits* are conceived as reference levels that should have a low probability of being exceeded and are designed to prevent stock declines through recruitment overfishing. *Targets* are reference levels providing management goals but which may not necessarily be met under all conditions. Although originally conceived as target reference points, the fishing mortality rate resulting in maximum sustainable yield and the corresponding level of equilibrium biomass are now commonly employed as limit reference points. Yield and spawning stock biomass per recruit analyses have been used to provide both limit and target reference points (Fogarty & Collie., 2009).

With the particularity observed in the Mediterranean' fisheries (the multispecificity of the marine exploitable resources) and the specific ways of harvesting, their management seems to be a very complicated task.

Despite the existence of strong works on stock assessment, deployed at national and regional levels (annual validated assessments by scientific experts (SAC-GFCM) and the STECF), a lot of studies indicate ***a worry situation*** of exploitable resources observed on commercial catches. The Historical management experiences of Mediterranean community-based fisheries were particularly effective in fostering both social cohesion and sustainable utilization of coastal resources. This figure contrasts with the current status of Mediterranean fisheries, where about **90%** of stocks are ***overexploited*** (Raicevich et *al*., 2018).

This condition conducts us to ask the following key question: ***Why we remain observing declines in landings of most Mediterranean stocks, despite all the efforts deployed in national and regional levels?***

Many hypotheses can be led to answer this problematic. Fogarty et *al*., (2009) assume that the failures in fishery management can often be traced to conflicting goals and objectives in the conservation, economic, and social dimensions. For example, the needs for conservation can be compromised by desires to maintain full employment opportunities in the fishing industry if this leads to political pressure to permit high harvest levels.

In the other side, the decisions took until now regarding the fisheries could be based on non-realistic parameters and the ways to define the basic biological reference points could be affected by external parameters such as mortalities rates or life history limitations of the stock.

In this respect, the aim of our study is to define if the natural selection pattern can conduct to different stock assessment conclusions and then impacts the fisheries regulations by dominating and changing completely the vision of a management plan.

The main objective is also, to describe the paradigm of Natural Mortality (M) and define how can population dynamic, be modelized by population' natural loss. notwithstanding it's complicated to give an accurate estimation to the key factor mentioned above.

Likewise, the present work will focus on the comparison of stock assessment using a recommended stock assessment' method representing in Extend Survivors Analysis (XSA), of two GFCM targeted species: the Red and Blue shrimp (*Aristeus antennatus "ARA"*) and the Red mullet (*Mullus barbatus "MUT"*) in the subareas (GSA 06) with different estimations of natural mortality (M) using a multitude of methods. Meanwhile, observing possible changes in fishing mortalities as well as the estimation of different biological reference points.

Finally, the purpose of this study is, therefore, to identify and discuss the need for further research in this area. The research project concludes by arguing conclusions with some useful results and recommendations suggested regarding the importance of each input parameter in the stock assessment process. Short forecasting is diagnosed to establish a possible raise for measuring management in the study area.

CHAPTER I:
Mediterranean Sea' Overview

I. GENERAL INFORMATION

I.1. DESCRIPTION OF THE MEDITERRANEAN SEA

The Mediterranean Sea is a semi-enclosed basin known as a large marine ecosystem with important biodiversity. It's the home of an unusually and diverse flora and fauna, which gives it the character to be a unique area in the world.

This isolated oceanic system as described by Schroeder et *al*., (2012), occupies an elongated area of about 2.5 million km^2 between Europe and Africa, and has only a restricted communication with the world ocean, through the narrow and shallow Strait of Gibraltar. It is further subdivided into two main basins, the Eastern Mediterranean (EMED) and the Western Mediterranean (WMED), communicating through the Sicily Channel. The geography and the bathymetry of the Mediterranean Sea are shown in (Figure 1). In spite of its limited size (0.7% surface, 0.25% volume of the global ocean), the basin is considered one of the most complex marine environments (Santinelli, 2015).

Due to its relatively small size, its geographical location, and its semi-landlocked nature, the Mediterranean Sea is very sensitive and responds quickly to atmospheric forcing and/or anthropogenic influences. Demographic growth, climate change, and overexploitation are exerting exceptional pressure on the Mediterranean environment, its ecosystems, services and resources. Further, it is a region where major oceanic processes occur, though on smaller scales than those occurring in the world ocean, as for instance the dense water formation (DWF) and the thermohaline circulation, known as the conveyor belt (Schroeder et *al*., 2012).

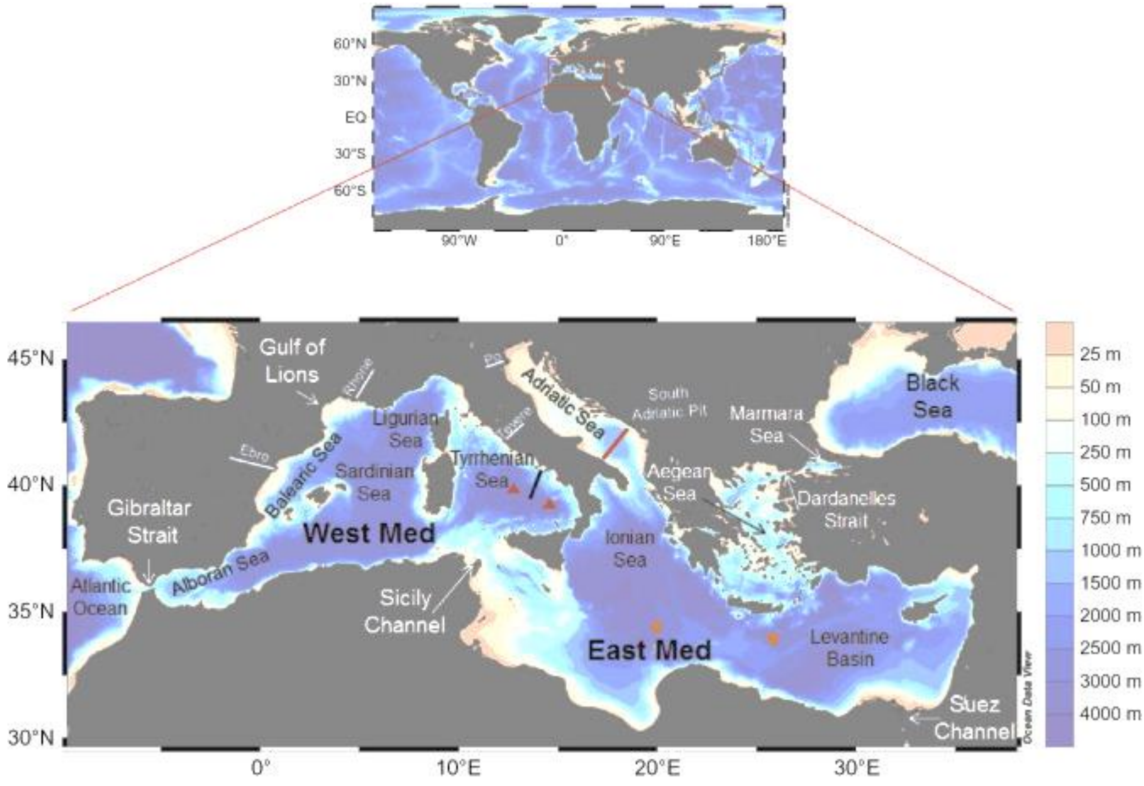


Figure 1: Geography and bathymetry of the Mediterranean Sea.

Source: (Santinelli, 2015)

Many studies have been undertaken to describe the Mediterranean's circulation, as it considered an important point for marine biodiversity. The species richness depends on the availability of sufficient nutrients and a healthy food web. The oligotrophy character of the basin, due to its geographical particularity is slightly persistence against the flow of the Atlantic Ocean entering through the Strait of Gibraltar.

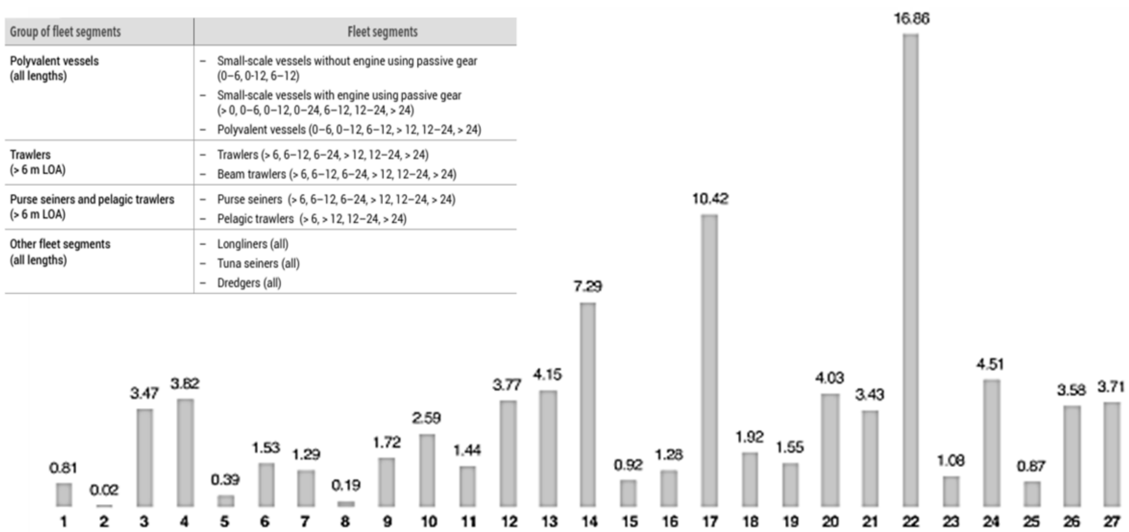
Atlantic surface waters, after having circulated within the Mediterranean in an anticlockwise direction, flow out denser and deeper below the entering waters in the form of the Mediterranean outflow water (MOW). As one progressively moves east into the Mediterranean Basin, oligotrophy increases whereas the productivity decreases (Mannino et *al.,* 2017).

The thermohaline circulation of the Mediterranean Sea exhibits strong seasonal and interannual variability, it is extremely complex, consisting of numerous eddies and current meanders. It is occupied at different levels by a number of water masses, either formed inside the sea or imported from the Atlantic Ocean (Schroeder et *al*., 2012).

I.2. THE MEDITERRANEAN FISHERIES

I.2.1. FISHING FLEET

The officially reported fishing fleet operating in the Mediterranean presents an uneven distribution (Figure 2) with the largest percentage (30.6 %) in by the eastern Mediterranean, followed by the central (26.4 %) and the western Mediterranean (17.3 %). Polyvalent vessels constitute the dominant vessel group in terms of numbers, representing 77.8 % of all vessels and then trawlers over 12m length overall (12–24 m LOA), polyvalent vessels (> 12 m LOA), purse seiners (> 12 m LOA), and longlines (> 6 m LOA) (FAO, 2018-b).



Group of fleet segments	Fleet segments
Polyvalent vessels (all lengths)	– Small-scale vessels without engine using passive gear (0–6, 0-12, 6–12) – Small-scale vessels with engine using passive gear (> 0, 0–6, 0–12, 0–24, 6–12, 12–24, > 24) – Polyvalent vessels (0–6, 0–12, 6–12, > 12, 12–24, > 24)
Trawlers (> 6 m LOA)	– Trawlers (> 6, 6–12, 6–24, > 12, 12–24, > 24) – Beam trawlers (> 6, 6–12, 6–24, > 12, 12–24, > 24)
Purse seiners and pelagic trawlers (> 6 m LOA)	– Purse seiners (> 6, 6–12, 6–24, > 12, 12–24, > 24) – Pelagic trawlers (> 6, > 12, 12–24, > 24)
Other fleet segments (all lengths)	– Longliners (all) – Tuna seiners (all) – Dredgers (all)

Figure 2: Percentage of operating fishing vessels by geographical subarea

Source: own compilation from (FAO, 2018-b)

I.2.2. FISHERIES PRODUCTION

The Mediterranean fisheries are distinguished by the multi-specificity, which remains a very discussable point for its management. In addition, the fisheries offer a great variability according to their location, their production methods as well as the adjustment of human communities to the environmental conditions (Papaconstantinou et *al*., 2000).

The average production varies considerably from a year to another, but generally, it presents a decreasing tendency of total reported landings in the most recent years. This signifies the underestimating of the real catches' patterns realized by different fishing gears, activating in the area and conduct to assume the presence of a huge lack of information about the nondeclared statistics all over the Mediterranean countries. Despite this reality, the decreasing trend tendency is noticed for the most fisheries in the world (see Figure 3), which will certainly be the case for the Mediterranean Sea, taking into account all the missing information previously defined.

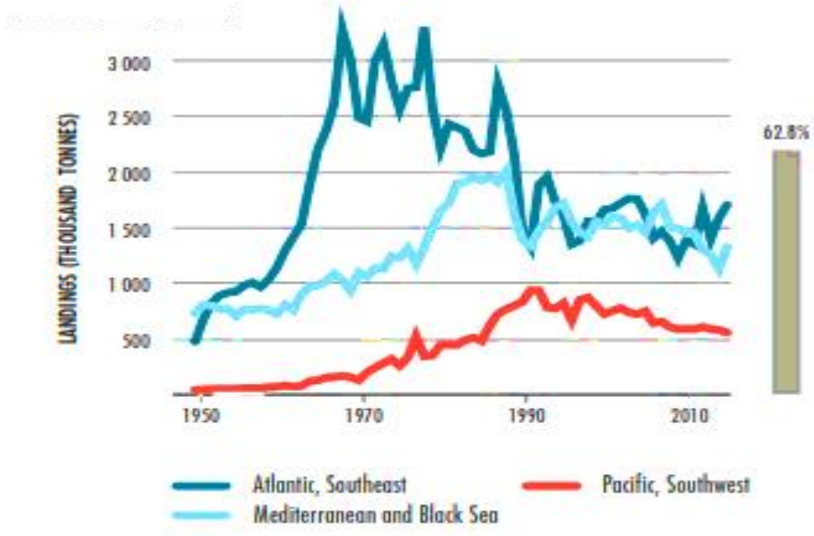
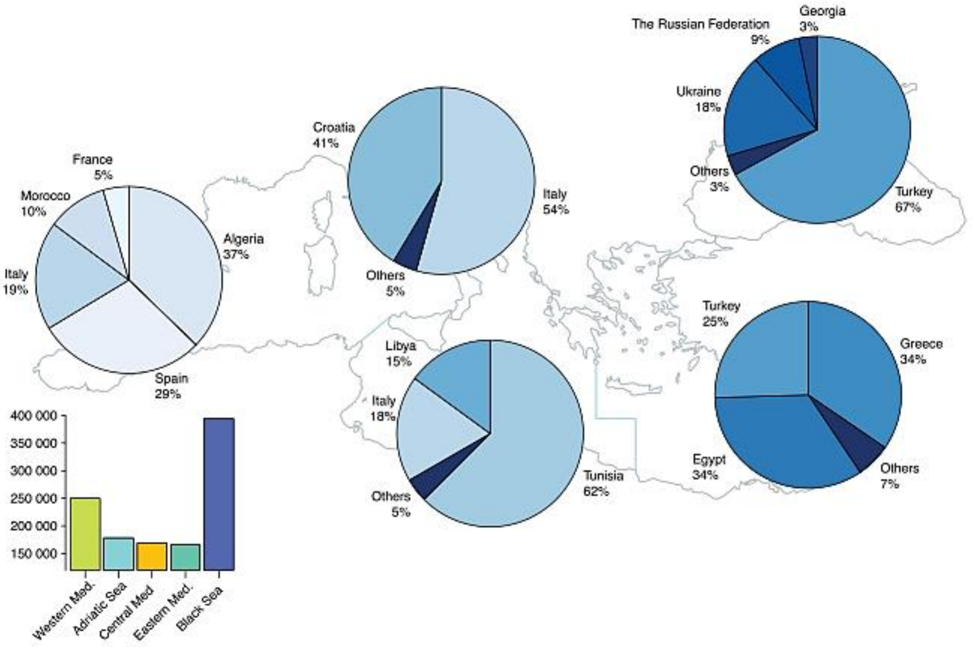


Figure 3: Patterns in world fish landings, for the years 1950–2015

Source: (FAO, 2018-a)

Across the GFCM area and in term of production statistics, the ranking of capture fisheries production in 2014–2016 is dominated by the western Mediterranean (Figure 4), with 265100 tonnes representing 22 % of the total landings in the area of application, followed by the Adriatic Sea and the central and eastern Mediterranean (193.500, 184. 500 and 180.800 tonnes respectively (FAO, 2018-b).



Note: Pie charts reflect the percentage of landings by country in the different GFCM subregions. The bar plot at the bottom-left represents absolute values of landings (tonnes) by GFCM subregion.

Figure 4: Landings by the GFCM subregion and by country 2014–2016

Source: (FAO, 2018-b)

I.2.3. FISHERIES STATUS AND FISHING AREAS

The situation of fisheries in the world is not so great as it appears. The global trends of marine resources present a very worry diagram.

Based on FAO's monitoring of assessed stocks, the fraction of fish stocks that are within biologically sustainable levels has exhibited a decreasing trend from 90 % in 1974 to 66.9 % in 2015. In contrast, the percentage of stocks fished at biologically unsustainable levels increased from 10 % in 1974 to 33.1 % in 2015, with the largest increases in the late 1970s and 1980s. In 2015, maximally sustainably fished stocks accounted for 59.9 % and underfished stocks for 7.0 % of the total assessed stocks (separated by the white line in Figure 5). The underfished stocks decreased continuously from 1974 to 2015, whereas the maximally sustainably fished stocks decreased from 1974 to 1989, and then increased to 59.9 % in 2015 (FAO, 2018-a).

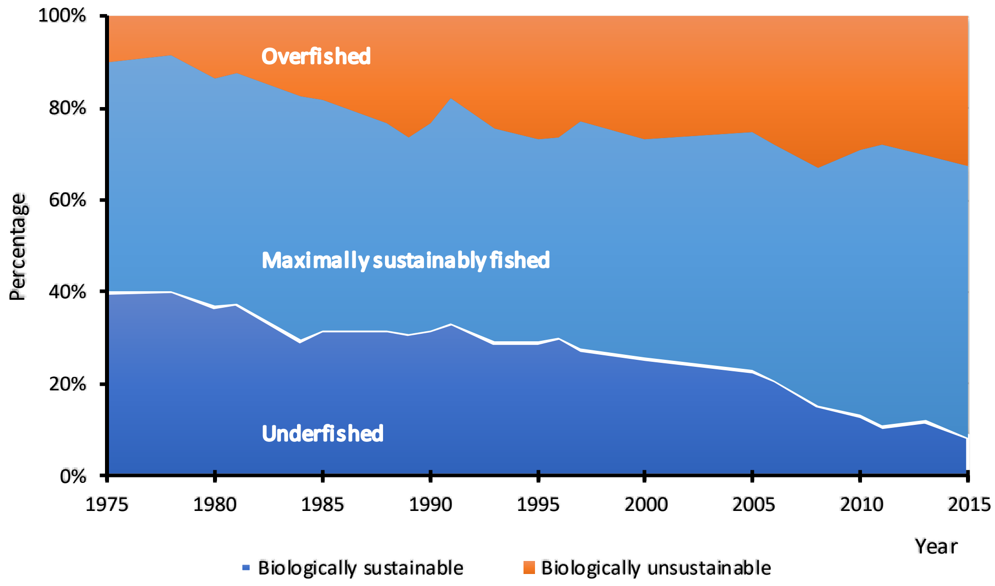


Figure 5: Global trends in the state of the world's marine fish stocks (1974-2015).

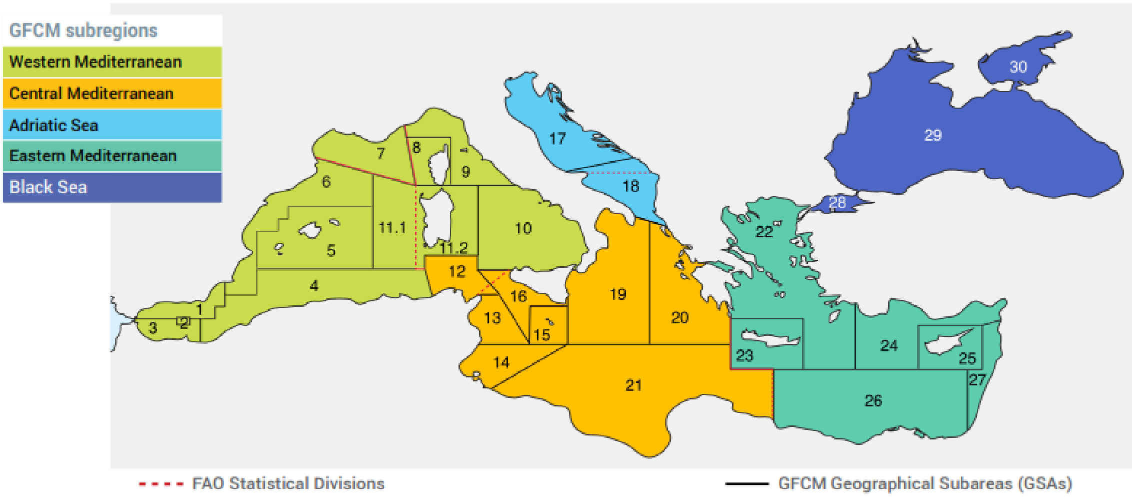
Source: own compilation from (FAO, 2018-a)

For the Mediterranean Sea, the fisheries status is a discussible point in different levels. The stock assessment is covering most of the area despite the fragmented information necessary for assessment.

Data are analysed at different levels of aggregation, and information is provided at different spatial scales in order to facilitate analyses at the regional, sub-regional and national levels. At the regional scale, summaries are presented to provide a general overview of relevant aspects of fisheries in the entire GFCM area of application (See Figure 6) (FAO, 2018-b).

The quality and coverage of scientific advice on the status of fishery resources have continued to increase, reaching around 50 % of the catches and providing a 40 % coverage of management units for priority species across the Mediterranean. About 78 per cent of Mediterranean and Black Sea stocks assessed are currently fished at biologically unsustainable levels (FAO, 2018-b), which means that the fishing mortality is higher than the target fishing mortality or the biomass is low than the target level.

In terms of biomass, 42 % of Mediterranean stocks, are considered to show low biomass, while the rest of stocks are considered to have intermediate or high biomass and Demersal stocks continue to experience higher fishing mortality rates (FAO, 2018-b).



GFCM GSAs

01 - Northern Alboran Sea	07 - Gulf of Lion	13 - Gulf of Hammamet	19 - Western Ionian Sea	25 - Cyprus
02 - Alboran Island	08 - Corsica	14 - Gulf of Gabes	20 - Eastern Ionian Sea	26 - South Levant
03 - Southern Alboran Sea	09 - Ligurian Sea and Northern Tyrrhenian Sea	15 - Malta	21 - Southern Ionian Sea	27 - Eastern Levant Sea
04 - Algeria	10 - South and Central Tyrrhenian Sea	16 - South of Sicily	22 - Aegean Sea	28 - Marmara Sea
05 - Balearic Islands	11.1 - Sardinia (west) 11.2 - Sardinia (east)	17 - Northern Adriatic Sea	23 - Crete	29 - Black Sea
06 - Northern Spain	12 - Northern Tunisia	18 - Southern Adriatic Sea	24 - North Levant Sea	30 - Azov Sea

Figure 6: GFCM area of application, subregions and geographical subareas

Source: (FAO, 2018-b)

The stock assessment advice is driven from both the GFCM and Scientific-Technical and Economic Committee for Fisheries (STECF). The European Union (EU) consider as basis of decision-makers, the independent stock assessment results of each organization.

According to the GFCM annual report (FAO, 2018-b), most stocks for which validate assessment are available, continue to be overfished in other sense to be outside the biologically sustainable limits. The mean ratio F/F_{MSY} of the assessed priority species demonstrate overall decreasing trends since 2012 on the other side, the trends of the Red mullet (*Mullus barbatus*) and the blue and red shrimp (*Aristeus antennatus*) exhibit generally a stable situation regarding the biomass but a decreasing trend of the harvest parameter (see Figure 7).

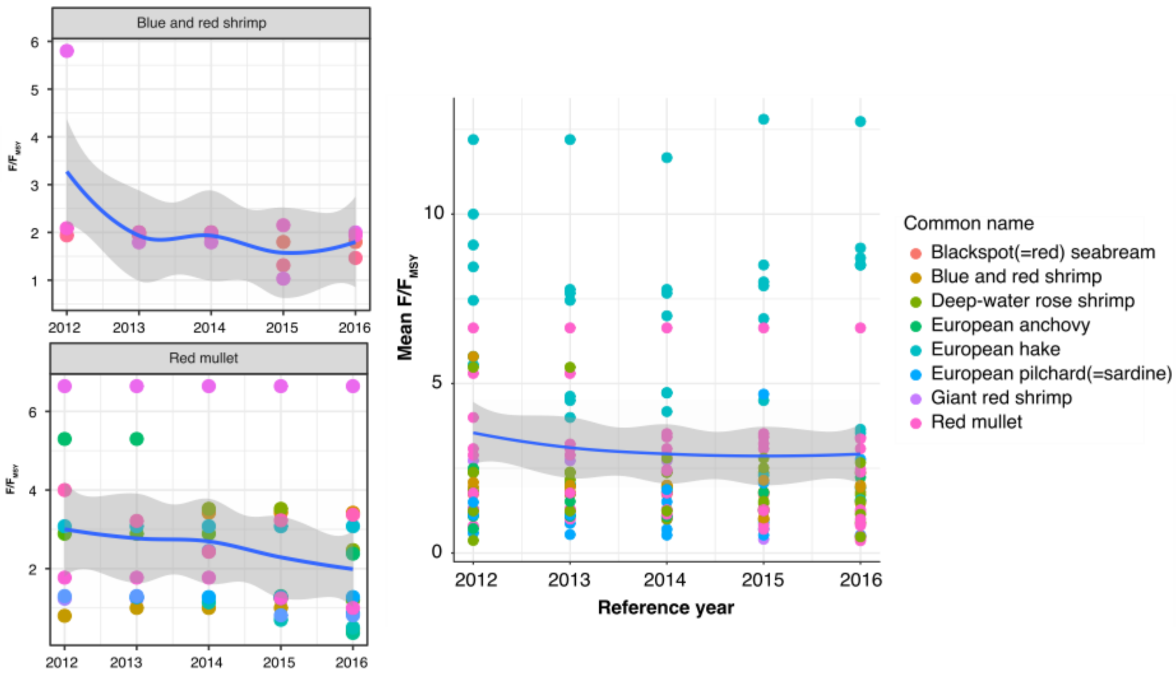


Figure 7: Overall trends (Loss smother) of the overexploitation index ($F_{current}/F_{MSY}$) of selected priority species in the Mediterranean Sea for the period 2012-2016.

Source: own compilation from (FAO, 2018-b)

A very pronounced difference in the trends situation is observed for the STEFC results in different sub-area (1, 5, 6). For all the species the situation appears to be in the way of recovering as it's noted the decrease of F trends. As concerns, the stocks of the undertaken species by this study, the results showed in (Table 1) demonstrate that the situation is unclear.

Table 1: Trends in biomass and fishing mortality of GSA 1,5 and 6 of selected priority species.

		GFCM			STECF		
Species	**GSAs**	**Year**	**F Trend**	**B Trend**	**Year**	**F Trend**	**B Trend**
Merluccius merluccius	1	2017	Stable	Increase	2014	No clear trend	No clear trend
	5	2017	No clear trend	No clear trend	2014	Stable	Decrease
	6	2017	Stable	Decrease	2014	Decrease	Decrease
Mullus surmuletus	5	2017	No clear trend	Decrease	2013	No clear trend	
Mullus barbatus	1	2014	Decrease	Stable	2014		No clear trend
	5	2012	No clear trend	No clear trend	2013	No clear trend	
Aristeus antennatus	1	2015	Stable	Stable	2014	No clear trend	No clear trend
	5	2017	No clear trend	No clear trend			
	6	2017			2014	Decrease	Increase
Parapenaeus longirostris	1				2012		Increase
	5	2017		No clear trend	2012	No clear trend	Stable
	6	2017			2013	No clear trend	No clear trend

Source: own compilation from (Sánchez Lizaso et *al.*, 2018)

In the other side, it is shown in the Kobe plot realized by (Kafaf, 2017), that the majority of stocks studied are in an overfishing and overfished situation which means that the level of intensity of fishing is very high than the target one in addition to that the stock size or the biomass is too low than the biomass reference point. For the two stocks of the red mullet and the red/blue shrimp, the situation seems to be in an overfishing state with a high pressure regarding the fishing mortality (Figure 8).

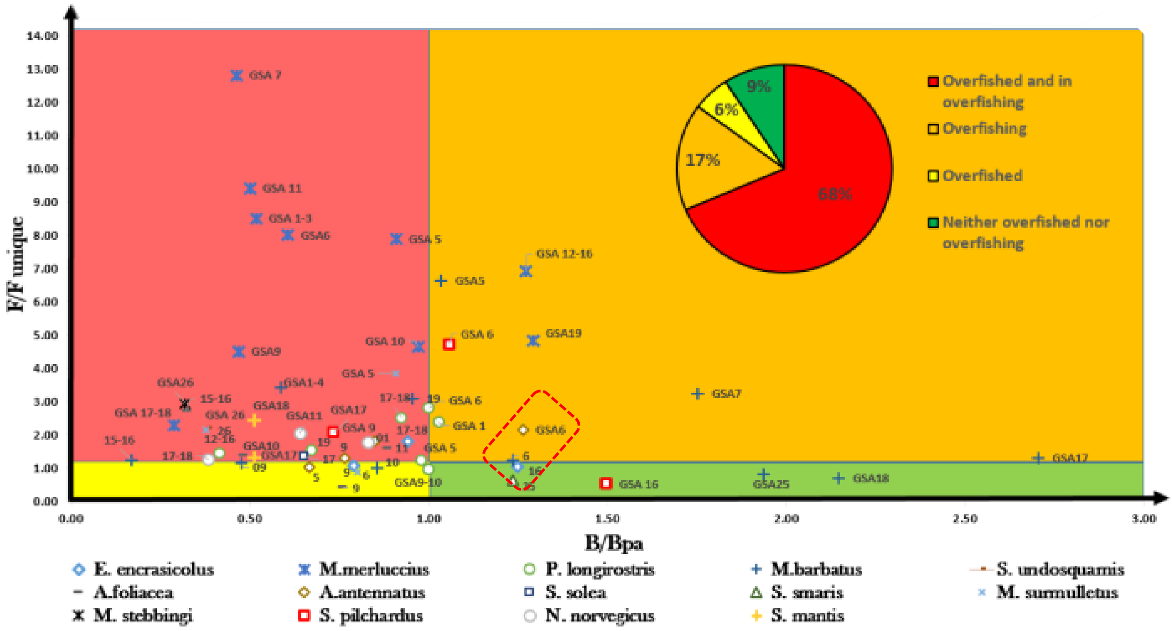


Figure 8: Kobe plot stock status of Mediterranean stocks (the pie chart is the percentage of each stock status).

Source: (Kafaf, 2017)

CHAPTER II:
Material and Methods

II. MATERIAL AND METHODS

II.1.TARGET SPECIES AND STUDY AREA

The study is conducted in the subareas 6 (GSA) of the GFCM subdivisions (See Figure 9). The stock units defined for the present study, are two target species of the GFCM stock assessment plan: the blue and red shrimp *Aristeus antennatus "ARA"* and the red mullet *Mullus barbatus "MUT". The high economic value, the interest, the very worrying situation regarding the fishing intensity and the availability of data on both stocks, justify our choice*.

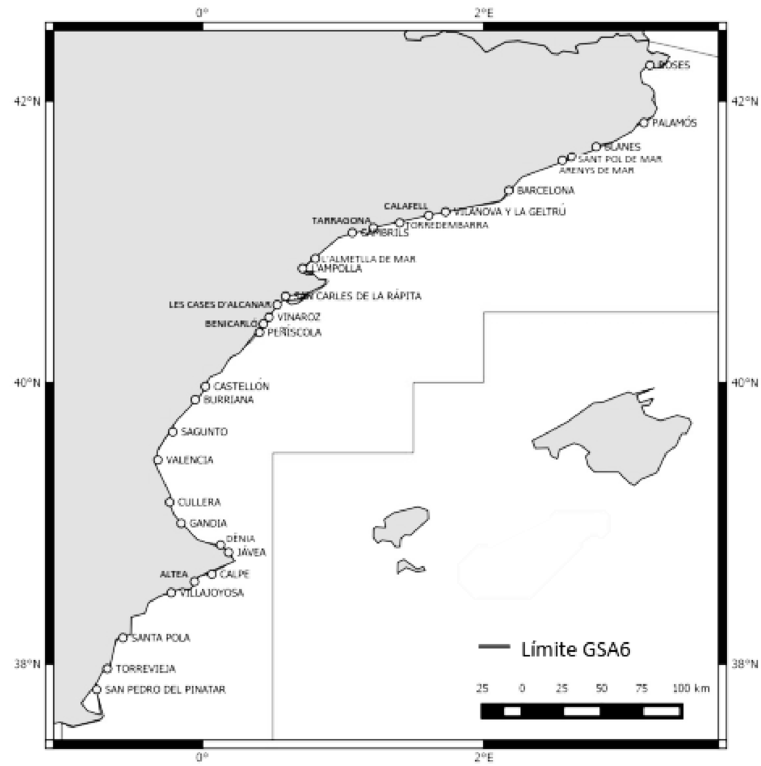


Figure 9: Study area limitation (the GSA 06 subarea)

Source: own compilation from (Querol, 2017)

Moreover, these two species are considered among the most target species of the trawl metier in the GSA6. The trawl fleets targeting the red shrimp are operating in the majority of ports in the whole area between 300-700 m depth. The red mullet's depth stratum is between 50-300 m, the fishery is characterized by a multitude of gears, nevertheless, only the trawl fisheries are considered for this study.

The total landings and the MEDITS Index of the shrimp and the red mullet are shown in (Figure 10). The period considered is between (2004-2017). As it appears clearly, the tendencies observed on the landings of the red shrimp (a) are in decrease from the year 2008 and this what has been confirmed by MEDITS index. This is not the case of the red mullet (b) who presents a slight increase starting from 2012 but return to decrease in the last year (2017) due to the decline of the vessel numbers activating in the area (Figure 11).

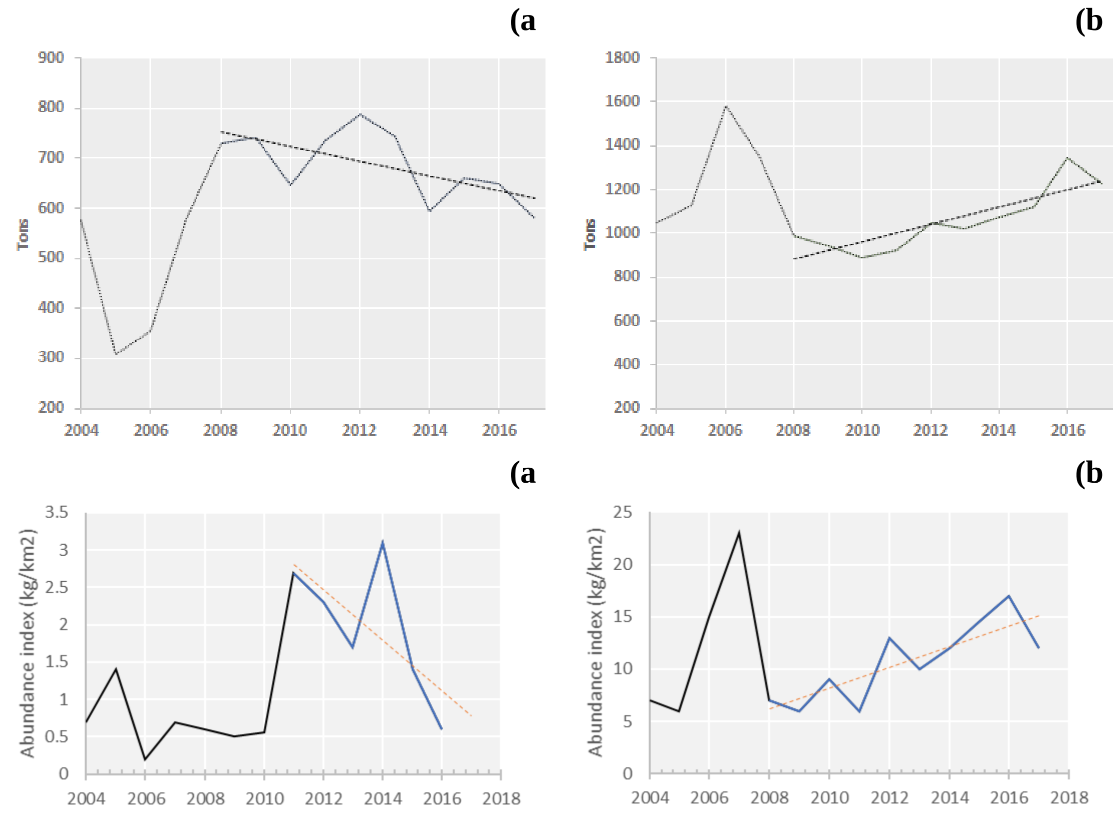


Figure 10: Historical landings and MEDITS abundance index (kg/km2) of the two species going back to 2004, based in GSA 06 {*Aristeus antennatus* (a), *Mullus barbatus* (b)}

Source: own compilation from (Secretaría General de Pesca, 2017) (Esteban et *al*., 2017 and García Rodríguez et *al*., 2017)

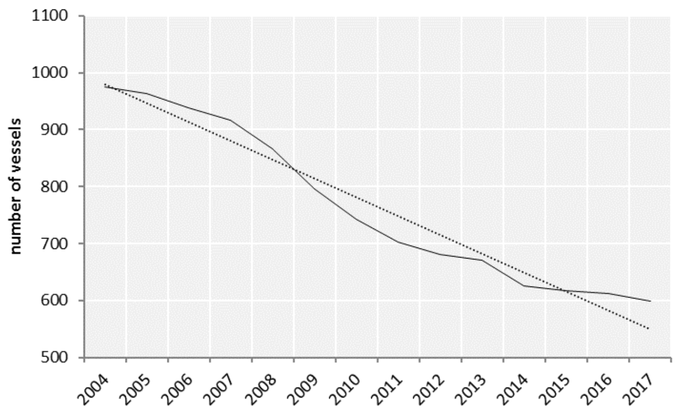


Figure 11: Evolution of Trawlers in the Spanish Mediterranean for the period (2004-2017).

Source: own compilation from (Secretaría General de Pesca, 2017)

II.2. SOURCE OF DATA

In order to get a valuable and real vision on the situation of the two stocks in the area of study, the data used were data from commercial catches in the main ports of the GSA 6, for the period from 1998 to 2017 for the red-blue shrimp (ARA) and from 2004 to 2017 for the red mullet (MUT). Also, the abundance index of the MEDITS (International Bottom Trawl Survey in the Mediterranean) released by the Instituto Espanol de Oceanografia (IEO) and described by (Esteban et *al*., 2017) & (García Rodríguez et *al*., 2017).

In other respects, the reports of the working groups of the GFCM in the subarea of interest were used to compare the eventual changes on the estimation of the biological reference points, which could be altered relating to the different changes on the Natural Mortality (M) and conduct to a sensitivity regarding the agreed fisheries management reference points of sustainable exploitation $F_{0.1}$ and F_{msy} which is defined in this case as the F_{max}.

The entry data used for the assessment are maintained the same for each scenario for both species (Table 2).

Table 2: Data entry used in the assessment process

	Growth parameters			***Length-weight relationship***	
	L_∞	***K***	***t_0***	***a***	***b***
***Aristeus antennatus* (Combined sex)**	77	0.38	-0.05	0.002038	2.506053
***Mullus barbatus* (Combined sex)**	34.5	0.35	-1.43	0.005600	3.248800

***Aristeus antennatus* (Combined sex)**		***Mullus barbatus* (Combined sex)**	
Age	**Proportion of matures**	**Age**	**Proportion of matures**
0	0.220	0	0.127
1	0.950	1	0.929
2	1.000	2	0.999
3	1.000	gp+	1.000
gp+	1.000		

II.3. SOFTWARE

For the present study, the composition data from fisheries and from the MEDITS survey were transformed first to age as it's considered more informative, using the program L2AGE4 and then analysed with the FLR framework (Fisheries Library in R), under R studio version 3.5.2 (2018-12-20) "*Eggshell Igloo*". However, the estimation of natural mortality' parameter (M) was undertaken in Excel 2016 of the most used methods in this study, as well as the use of the PRODBIOM spreadsheet realized and developed by Abella et *al*., (1998).

II.4. METHODS

II.4.1. NATURAL MORTALITY (M) CALCULATION

The estimation of natural mortality rates remains a very complex task in fisheries stock assessment. By definition, natural mortality (M) accounts for decreasing stock abundance potentially due to numerous other causes apart from fishing, including e.g. predation, cannibalism, disease, spawning stress, starvation, and senescence. As direct measurements are usually impossible to obtain. (Beyer et *al*., 1999).

In addition, Lee & *al*., (2011) consider that Natural mortality, one of the most influential quantities in fisheries stock assessment and management. The magnitude of this parameter relates directly to the productivity of the stock, the yields that can be obtained, optimal exploitation rates, and reference points.

Admittedly, great efforts into quantifying natural mortality and its large-scale patterns of variation across species, but most theory has treated it as an externally set parameter, usually M=0.2 an^{-1} (Jørgensen, C., & Holt, R. E., 2013).

Current practices in stock assessments which take into account variation of M with ages seems to be either, to adopt discrete M values for a series of ages based to supplementary biological data, or to postulate a continuous mathematical function for the change in natural mortality with age (Caddy, 1991).

In our case, the estimation of the mentioned parameter (M) was elaborated by different methods that take into account or not the age-dependency of the concerned stocks but also its nature due to the existence of methods that are limited only to fishes.

II.4.1.1. AGE-INDEPENDENT METHODS

A significant number of empirical equations and methods have been agreed to estimate natural mortality rates. Some take into account the relation between the maturity and mortality, others consider the reciprocity with maximum age and certain, express the multiple regression and reflect that M for a stock is a function of combination between Von Bertalanffy growth parameters in addition to the abiotic factors like the environmental temperature.

For our case, only four methods have been used by taking into consideration the specificity and the application conditions of each one. The Scientific, Technical and Economic Committee for Fisheries (STECF) recommend the use of methods with less sensitive to the Von Bertalanffy growth parameters when the uncertainty of these factors is high.

1) GISLASON (2008)

Gislason et *al*., (2010) have demonstrated the existence of a huge dependency between the estimation of the natural mortality and the Von Bertalanffy growth parameters as well as the temperature of the area from where the individuals have been sampled. The estimates of the natural mortality (M) combines with a validate growth parameters.

For that, the estimation of the natural mortality according to different models where the parameters of the equation (1) were changed has conducted the researcher to advocate the model which use the parameters mentioned below.

$$\ln(M) = a + b \ln L + c \ln L_\infty + d \ln K - \frac{e}{T} \qquad (1)$$

Entrance parameters => $\begin{cases} a = 0.55 \\ b = -1.61 \\ c = 1.44 \end{cases}$

The parameters d and $\frac{e}{T}$ are assumed negligible for fitting this model.

2) LORENZEN (1996)

The method of Lorenzen has been developed under the assumption of the closest relation between body weight and natural mortality. This method is used only for fishes as the author studies the natural loses and weight relationships in different natural ecosystems. The equation (2) is described as well as its different associated parameters (Lorenzen, 1996).

$$M_w = M_u W^b \qquad (2)$$

Where: M_w is the natural mortality rate at weight W

M_u is the natural mortality rate at unit weight

and b is the allometric scaling factor

3) GULLAND (1987)

Based on McGurk (1986) theory, Gulland tried to explain the relationship between the length of fish and the natural losses. The equation (3) was developed to be used only for fishes as it was recommended by (Ragonese et *al*., 2018) and where M' is considered as the limiting value approached by the biggest fish (Gulland, 1987).

$$log_{10}M = logM' - 0.5 \log \left({}^{W}/_{L_\infty} \right)$$

or in terms of length $$log_{10}M = logM' - 1.5 \log \left({}^{1}/_{L_\infty} \right) \qquad (3)$$

4) PAULY (1980)

For this method, Pauly mentioned that natural mortality is directly related to the Von Bertalanffy growth parameters (L_∞, K, t_0) and the main temperature (T°C) of the environment related to the living area of the specie. The use of this equations (4) or (5) is straightforward as well as Von Bertalanffy parameters are available (Simpfendorfer et *al*., 2012).

The equation is given as:

$$\log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T \quad (4)$$

And the same relation based on weight:

$$\log M = -0.2107 - 0.0824 \log W_\infty + 0.6757 \log K + 0.4627 \log T \quad (5)$$

II.4.1.2. AGE-DEPENDENT METHODS

For this section, the estimation of the natural mortality (M) depends on the age knowledge as it's considered that the mortality rate changes within the different life stages of the species. Two of the most conventional methods and recommended by the International Council for the Exploration of the Sea (ICES) and the General Fisheries Commission for the Mediterranean (GFCM-FAO), for the stock assessment process, are used for this work.

1) CHEN & WATANABE (1989)

Chen & Watanabe (1989) recognized that the natural mortality in the fish population, like most animal populations, should have a U-shaped curve (Figure 12) when plotted against age (bathtub curve) which is obtained by two distinguishable functions (6) that describe respectively the falling mortality rate in early life and the increase of that parameter towards the end of life. (Simpfendorfer et *al*., 2012).

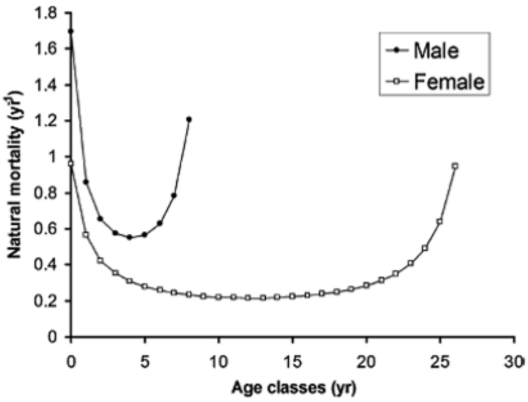


Figure 12: Example of the application of the bathtub U-shaped to estimate the age-dependent instantaneous natural mortality (M).

Source: (Ragonese et *al*., 2018)

$$M(t) = \begin{cases} \dfrac{K}{1 - e^{-K(t-t_0)}} & t \leq t_M \\ \dfrac{K}{a_0 + a_1(t - t_M) + a_2(t - t_M)^2} & t \geq t_M \end{cases} \tag{6}$$

Where

$$\begin{cases} a_0 = 1 - e^{-K(t_M - t_0)} \\ a_1 = Ke^{-K(t_M - t_0)} \\ a_2 = -\frac{1}{2}K^2 e^{-K(t_M - t_0)} \end{cases} \quad \text{and} \quad t_M = -\frac{1}{K}\ln\left(1 - e^{Kt_0}\right) + t_0$$

t_M represents the maximum age of reproduction, while the constant K and t_0 refer to parameters of the Von Bertalanffy growth model. The authors require only the $t_0 < 0$ constraint and assume that M declines from high values (at ages close to t_0) to a minimum at the age corresponding to the ecological longevity.

2) ABELLA AND CADDY (1997): PRODBIOM PROGRAM

The idea behind the development of this method has been supported by the assumption demonstrated by (Caddy, 1991) and which is based on the considerations about production and losses of biomass due to natural mortality. Beverton and Holt (1956) showed that the constant instantaneous adult mortality rate for a species is proportional to the reciprocal of the mean age (t) of the population and M drop rapidly to very low levels for longer-lived species (Caddy, 1991).

The approach of Abella et *al*., (1998) allows the estimation of M vectors with age/size that show higher values of M in early stages and for juveniles, followed by a progressive decline with age in the adult phase were considered as the most realistic and useful, especially in the case of the Mediterranean stocks exploited at a very early age of first capture. It has been stressed that the existence of reciprocal relationships between age and M are the only ones that can explain the actual demographic structure at sea and also the persistence of some stocks that have suffered a very strong fishing pressure since many years and where the exploitation of early life stages occurs. The use of this method is endorsed by the STECF to calculate natural mortality (M) (Di Natale, et *al*., 2009).

$$M_{(t)} = M_a + \left(\frac{\beta}{t}\right) \qquad \left(t > 0; \quad M_{(t)} > 0\right) \tag{7}$$

Where : $\begin{cases} M_{(t)}\ is\ the\ age - time\ specific\ mortality\ rate \\ \beta\ \ is\ a\ corvature\ parameter \\ M_a\ is\ the\ asymptotic\ mortality\ at\ some\ hypothetical\ maximum\ age \end{cases}$

M_a is generally lower than the constant adult M observed for the stock and it's also remarked its mathematical non-biological nature (i.e. it might also assume negative values) (Ragonese et *al*., 2018).

Caddy (1991) suggest that the age-specific death rate $M_{(t)}$, rapidly converges with age on a constant, asymptotic mortality rate for adult fish M_a which may even be negative, especialy for short-lived species.

II.4.2. Stock assessment methods – The FLXSA

Extended survivors' analysis (XSA; Darby and Flatman, 1994) has been used for catch-at-age analysis for most stocks' analysis. The implementation under the version (FLXSA) incorporated in the FLR package has the ability to produce tuning diagnostics output (ICES, 2008), to perform data analysis, sensitivity, retrospective analysis, reference point calculations and forecasting or projections.

The essential ideas of the Survivors method introduced by Doubleday (1981) are: (1) treat the abundance of the survivors of each cohort as the principal variables to be estimated, by a least-squares procedure; (2) estimate population abundance for all other ages and years by VPA (in practice the Cohort Analysis of Pope, 1972), using estimated survivors as the terminal populations; (3) calibrate the abundance indices (CPUE data) using the population abundance estimates and a simple model for catchability (for each ''fleet''); and (4) use the independent estimates of population obtained from each set of calibrated abundance indices, for all ages in each cohort, as the basis for estimating survivors (Shepherd, 1999).

Lassen & Medley (2001), assume that the XSA is based on an iteration procedure of the functional type. The data are catch-at-age in numbers by age and by year supplemented by stock abundance indices. However, the approach is restricted as only age dis-aggregated abundance indices can be used. The basis of the method is the link between the population and the abundance index through the catchability q. The CPUE values are all corrected to refer to the stock at the beginning of the year using the formula (8)(8) :

$$Cpue_{ayf} = Cpue^{\ obs}_{ayf} / \left[exp\left(-\alpha\left(F_{ay} + M_a\right)\right) \frac{1 - exp\left(-(\beta - \alpha)(F_{ay} + M_a)\right)}{F_{ay} + M_a} \right] \qquad (8)$$

Where: α and β are the start and end point in time of the observation given as a fraction of the year.

In another way, the analysis of a set of catch-at-age data where $\boldsymbol{y}$ indexes **"years"** and $\boldsymbol{a}$ indexes **"ages"**, and $\boldsymbol{f}$ indexes **"fleets"**. These indices are assumed to be related to the population abundance, according to a simple constant catchability model (for the recruited age groups) (9) :

$$u(y, a, f) = q(a, f)A(y, a, f)P(y, a) \qquad (9)$$

where P denotes population size at the beginning of each year, and A is the averaging factor related to the average population during the period when the fishing takes place to that at the beginning of the year. The equation (8) is written by (Shepherd, 1999) as equation (10):

$$A(y,a,f) = \frac{exp\{-\alpha Z(y,a)\} - exp\{-\beta Z(y,a)\}}{(\beta - \alpha)Z(y,a)} \quad (10)$$

Where Z represents the total mortality.

The XSA iteration starts with an initial guess of the number of survivors (population at the end of the year of the oldest age group included in the analysis) and M. The XSA then applies a standard VPA to the catch-at-age and year data to provide stock sizes N. Based on these stock sizes the catchability q and the exponent γ can be estimated by linear regression (Lassen & Medley, 2001) (11):

$$\ln N_{ay}^{VPA} = \frac{1}{\gamma_{af}} \ln CPUE_{ayf} - \frac{\ln q_{af}}{\gamma_{af}} \quad (11)$$

When the catchability and the exponent in the CPUE–stock relation has been determined, the next step is to correct the stock estimate (12):

$$\ln N_{ayf}^{corr} = \frac{\ln CPUE_{ayf} - \ln q_{af}}{\gamma_{ay}} \quad (12)$$

The authors showed that each abundance index estimates the stock in numbers by age and by year. The results are then averaged to provide a new starting point for a new VPA based on calculating the number of survivors of the oldest age group included in the catch-at-age analysis (13):

$$\ln N^{survivors} = \ln \left[\frac{CPUE_a}{q_a}\right] - F_{a,cum} - M_{a,cum} \quad (13)$$

Where the fishing mortality (F) and natural (M) are cumulative over age (a) until the oldest age included in the analysis. For a given cohort, there will be a number of such estimates of survivors. These come from different age groups observed in the same abundance index and from different indices (e.g. research vessel surveys). The XSA combines these weighted estimates into a single estimate of the survivors of that cohort and then introduce it into a VPA of the catch in numbers by age and by year thereby obtaining stock in numbers and fishing mortality. This concludes the iteration loop. The next iteration loop begins by using these estimates to calculate the catchabilities (q_a) by age and by index type. The whole process is repeated until convergence. The weights used for the survivor estimates are the inverse prediction variance around the regression carried out to estimate the catchabilities, multiplied by $F_{a,cum}$ (Lassen & Medley, 2001).

The employment of this method within R consists on the use of algorithms which takes into account the different equations cited above and the practical considerations can be resumed in the following steps, as it recommended by (Shepherd, 1999) :

- Read data
- Set prior weights, etc.
- Initialize survivors
- Begin iterative loop
    - Do VPA (cohort analysis)
    - Calculate Z, ECZ, etc.
    - For each fleet, and age
        - Calculate weighted mean reciprocal catchability and variance thereof
    - Next fleet, and age
    - Adjust weights {estimate the variance of ln(r)} For each fleet, age, and year
    - Calculate estimated populations
    - Next fleet, age, and year for each cohort
        - Calculate weighted mean survivors
    - Next cohort
- Repeat loop
- Print results, residuals, diagnostics, etc.

II.4.2.1. INPUT DATA

The Stock assessment conducted by the XSA has been performed by sex combined with an age range from 0 to 4+ for the two species (ARA, MUT). No Discards were included and the tuning was carried out using the survey data (MEDITS index), the breakpoint is set at the year 2013 where the scientific research vessel has been replaced.

The catch data and tuning file used as inputs are from 1998 to 2017 for the red-blue shrimp (ARA) and from 2004 to 2017 for the red mullet (MUT). The FLQuant objects created are resumed in the following schema (Figure 13, Figure 14).

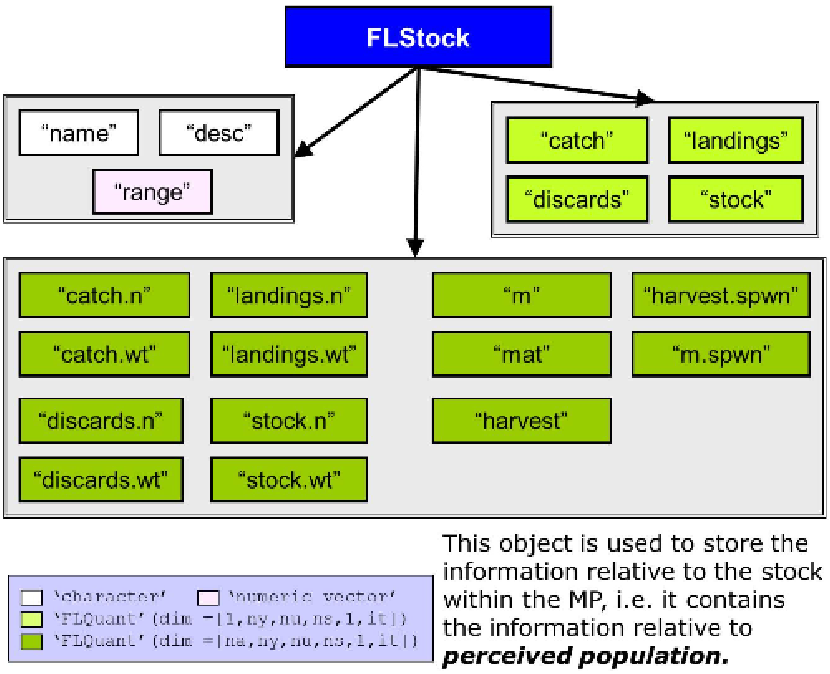


Figure 13: FLStock object

Source : (García et *al.*, 2019)

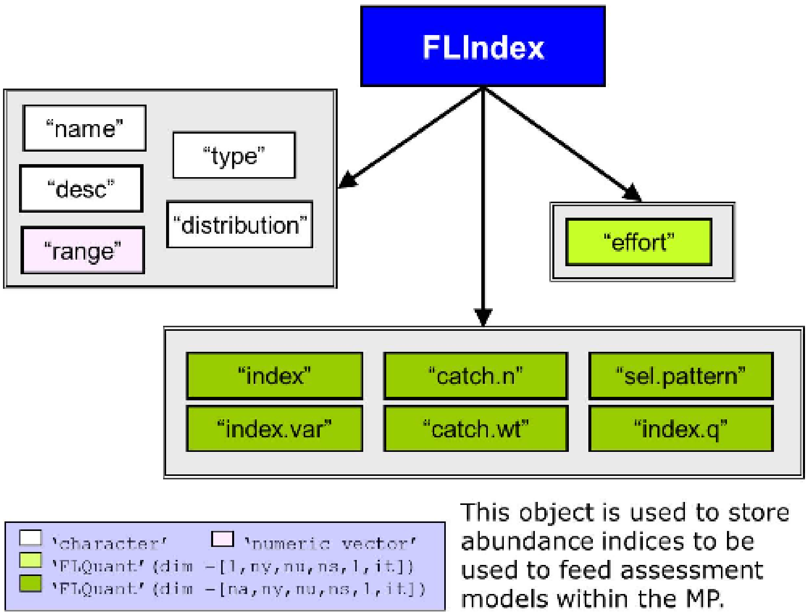


Figure 14: FLIndex object

Source : (García et *al.*, 2019)

II.4.2.2. THE FLXSA CONTROL OBJECT

The `FLXSA.control` object contains the following settings (see Table 3): Shrinkages, Shrink year, Selectivity, catchability and Minimum Standard Error for survivor’s estimates. These configurations have conducted several scenarios when running the XSA with changing mortalities.

```
FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=0.5,
rage=0, qage=1, shk.n=TRUE, shk.f=TRUE, shk.yrs=3, shk.ages=3,
window=100, tsrange=20, tspower=3, vpa=FALSE)
```

Table 3: Signification of different settings to run the FLXSA control object (García et *al*., 2019)

X	An object of class FLXSA. If specified the control object is initialised with the same settings as the XSA analysis stored in the object.
tol.	Convergence tolerance. The model is considered to have converged once the sum of the absolute differences in terminal F values between two successive iterations is less than the specified value
Maxit	The maximum number of iterations that the model can run
min.nse	The minimum standard error to be used for inverse variance weighting of the survivors' estimates
Fse	User-defined standard error when shrinking the mean F
Rage	The oldest age for determining catchability at age
Qage	ages will be set to the value of catchability at this age.
shk.n	Boolean. If TRUE apply shrinkage to the population mean. Applies to the recruiting ages only.
shk.f	Boolean. If TRUE apply shrinkage to the mean F.
shk.yrs	The number of years to be used for shrinkage to the mean F.
shk.ages	The ages over which shrinkage to the mean F should be applied.
window	The specific year range for which the model should be run.
tsrange	The number of years to be used in the time series weighting.
tspower	The power to be used in the time series taper weighting.
vpa	Boolean. If TRUE, use VPA to calculate historical values of F and population abundance. If FALSE, use cohort approximation.

II.4.2.3. RETROSPECTIVE ANALYSIS

This type of analysis is considered to identify years which lead to poor projections. It has been used extensively to investigate the performance of particular assessments and it is part of standard ICES assessment procedure (Lassen & Medley, 2001).

The retrospective patterns are most problematic of fisheries management when fishing mortality is consistently underestimated and abundance overestimated or when the opposite direction occurs (Kilduff et *al*., 2009).

II.4.3. STOCK-RECRUITMENT RELATIONSHIP

The stock-recruitment relation is required for discussing reference points, as well as these points, are estimated following different levels of spawning stock biomass (SSB) and the number of recruits (R).

Traditionally, there are two different S-R models in fish stock assessment: the Beverton & Holt model (1957) and the Ricker model (1954) (Lassen & Medley., 2001).

The same authors describe the Beverton & Holt and Ricker models respectively in equation (14) and (15).

$$R = \frac{\alpha}{1 + \beta / SSB} \qquad (14)$$

Where α is the asymptotic maximum recruitment obtained from the spawning stock biomass (SSB) and β represents the spawning stock biomass when the recruitment R is half of the maximum potential. The biological concept behind this model is that the egg production (assumed proportional to the SSB) approaches a limit which is set by a density-dependent mechanism, so in other manner by the natural mortality in different life stages.

For the Ricker model (see equation (15)) the recruitment curve is based on feedback mechanism which could be a result of cannibalism where the adults have a negative impact on survival success.

$$R = \alpha \, SSB \, e^{-SSB/K} \qquad (15)$$

The parameter α controls the sloop at origin and the $K$is the SSB when the recruitment is maximum.

II.4.3.1. MODEL SELECTION CRITERIA

The evaluation of the model which fit well to the data analysed refers to check within a statistical model that could describe best and adequately the data set to examination with less mean square errors, among other models. In another manner, *what criterion can be used to select the best model?*

To ensure the answer for this question in the present study, the main models used are two most commonly used criteria in model selection “the *Akaike information criterion* (AIC)” and the “*Bayesian information criterion* (BIC)”. The value is calculated for every candidate model and the “best” model is the candidate model with the smallest AIC or minimum BIC (Fabozzi et *al*., 2014).

II.4.4. REFERENCE POINTS FOR FISHERIES MANAGEMENT WITH FLBRP

In order to define a great management strategy for fisheries, it’s necessary to define boundaries that the fishing mortality level or even the biomass could reach and have not to exceed. These boundaries represent the reference points (RP) which allow important catch weight whilst ensuring the stock’s conservation. Smith, et *al*., (1993) commented that different harvest strategies lead to different fishery characteristics and stock conditions and, consequently, certain reference points may be better suited than others to meet a given set of fisheries management objectives.

Not all reference points were viewed as equally valuable. It can be most useful if they are based on a good estimation of parameters and stable characteristics, for example, those employing simple parameters may be more useful than those employing parameters subjects to greater uncertainties, at least they should be durable and treatable (Smith, et *al*., 1993).

The World Summit on Sustainable Development (WSSD 2002) committed signatories to maintain or restore stocks to levels that can produce the Maximum Sustainable Yield (MSY). In addition, the precautionary approach (FAO 1996) requires the use of limit and target reference points to constrain harvesting within safe biological limits while accounting for the major sources of uncertainty (Hamon, et *al*., 2017).

For this study, the biological reference points (BRP) have been estimated using the FLBRP algorithms. For that matter, the Limit reference points such us $F_{0.1}$, F_{max}, and F_{MSY} (see Figure 15) which represents the extension of F_{max}, when yield=recruitment, were studied to define the main situation of the blue & red shrimp and red mullet regarding the changes in natural mortality pattern as it was mentioned as objective of this work.

The indicator MSY has been criticised as not being a robust management objective since it may lead to unsustainable and/or less than optimal management because of uncertainties associated with the interpretation of data and the simplifying assumptions made when modelling biological processes (Rosenberg and Restrepo 1994). Hilborn (2010) introduced the concept of *pretty good yield* corresponding to at least 80% of the theoretical *MSY*. The range of *Fs* leading to the pretty good yield can be considered a region around the estimated F_{MSY} (Hamon, et *al*., 2017).

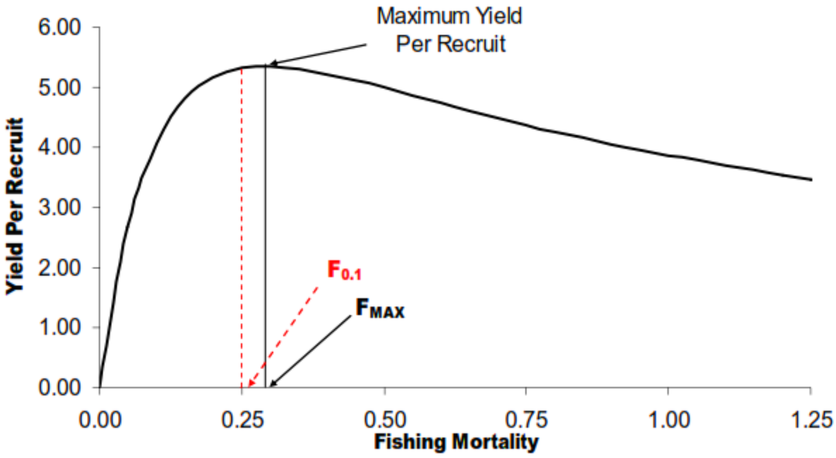


Figure 15: Yield-per-recruit (YPR) analysis.

Source: (Kilduff et *al.*, 2009)

Regarding this reference points, the WGGFCM (García Rodríguez, et *al.*, 2017) considered that the Stock Status could be defined, based on Fishing mortality as follow:

1) **N - Not known or uncertain** – Not much information is available to make a judgment;
2) **U - Undeveloped or new fishery** - Believed to have a significant potential for expansion in total production;
3) **S - Sustainable exploitation**- fishing mortality or effort below agreed fishing mortality or effort-based Reference Point;
4) **IO –In Overfishing status**– fishing mortality or effort above the value of the agreed fishing mortality or effort-based Reference Point. An agreed range of overfishing levels is provided;

   The range of Overfishing levels is defined:
   - If Fcurr/$F_{0.1}$ is below or equal to 1.33 the stock is in **(O_L): Low overfishing**
   - If the Fcurr/$F_{0.1}$ is between 1.33 and 1.66 the stock is in **(O_I): Intermediate overfishing**
   - If the Fcurr/$F_{0.1}$ is equal or above to 1.66 the stock is in **(O_H): High overfishing**
5) **C- Collapsed**- no or very few catches;

II.4.5. SHORT TERM FORECASTS

Short-term prognoses have been carried out in FLR using FLash. Typically, when running Short Term Forecasts, means the exploration of several different future F scenarios of the last 3 years (Poos, & Hamon, 2017).

- The first scenario was a total fishery closure (F=0);
- F at F status quo (F_{SQ}), which is equal to the mean of the last 3 years;
- F at Fmsy;
- F at $F_{0.1}$;
- Making a projection with $F_{30\%}$.
- Making several estimations with the multiplication of F_{SQ} with a factor of 0.2

CHAPTER III:
Results and Discussions

III. RESULTS AND DISCUSSIONS

III.1. THE RED AND BLUE SHRIMP (*Aristeus antennatus* "ARA")

RESULTS

III.1.1. NATURAL MORTALITY RESULTS

The estimation of the natural mortality parameter (M) with different methods gave the results presented in Table 4, Table 5 and in Figure 16, Figure 17.

Table 4: Annual Natural Mortality (M) Scalar values

Method	Gislason	Lorenzen	Gulland	Pauly
M ($year^{-1}$)	0.37	0.83	0.66	0.51

Table 5: Annual Natural Mortality (M) per age

Method / Age	Chen & Watanabe M ($year^{-1}$)	Abella & Caddy M ($year^{-1}$)	M used in stock assessment (2017) M ($year^{-1}$)
0	2.09	1.14	1.58
I	1.15	0.63	0.91
II	0.7	0.45	0.58
III	0.55	0.39	0.47
IV	0.48	0.35	0.41

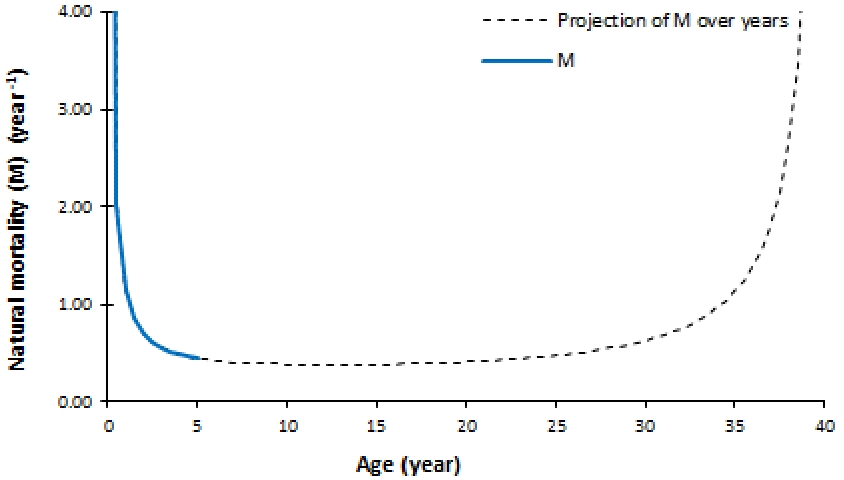


Figure 16: The bathtub U-shaped to estimate the age-dependent instantaneous natural mortality (M) of *Aristeus antennatus* in GSA 06.

The application of Abella & Caddy (1997) method using ProdBiom Program assigns various results concerning the asymptotic mortality (Ma). The choice of the best Ma was justified by minimising the quadratic differences among the values obtained with several Ma using solver. The different vectors of natural mortality obtained are illustrated in (Figure 17) and the dashed Ma indicates the value chosen.

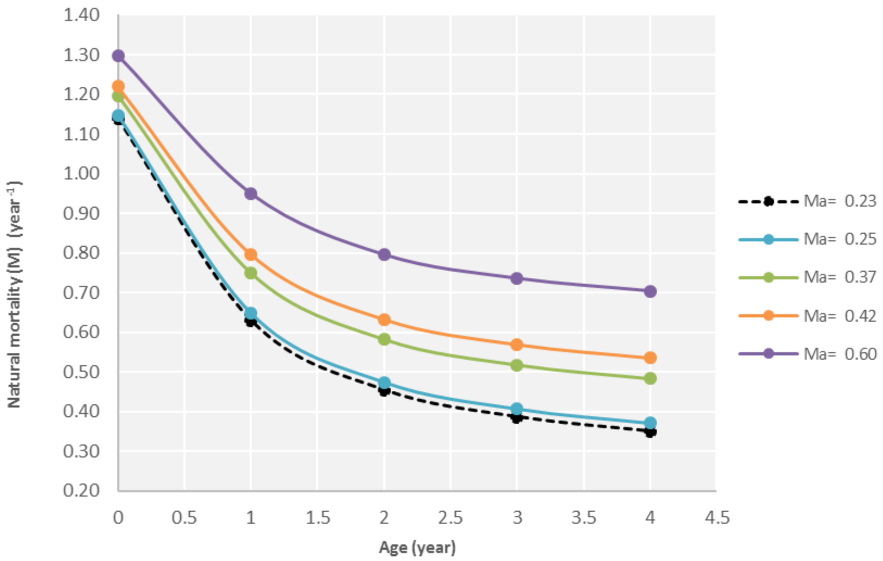


Figure 17: Different values of M obtained using the ProdBiom model with various asymptotic mortality (Ma) on *Aristeus antennatus* in GSA 06.

III.1.2. THE XSA RESULTS

The analysis of landings ongoing from 2017 to 1998 (Figure 18) presents three important phases in the history of the fishery. The first phase draws an increase of landings followed by several decreases from 2003 to 2005 explained by the reduction in the number of trawlers over the ten last years as it is shown before in (Figure 11). A slight diminution is shown from the year 2009 which represents a breakpoint of the fishery and typified by the introduction of the quadratic mesh instead of the diagonal mesh. However, the situation could be generated also by many other factors which can contribute to these declines on the catch, such as environmental changes. The comparison of catches in numbers by ages illustrated in (Figure 19), demonstrates the predominance of young shrimps, from 0 to 3 age groups but in the same time the analysis of residuals (Figure 20) demonstrates a weak coeficient of determination for the young groups wich is relativly the same for the other groups and this is probably due to fitting problems.

The sensitivity analysis illustrated with the residuals diagnostic in (Figure 21 & Figure 22), reveals that the best setting to use the run is considered for **r0q1** which has demonstrated the lowest residuals value comparing with other controls. In addition, it has been observed the dominance of negative values for younger ages at the most recent periods and which may be explained by the behaviour of these individuals with respect to the gear or the shift in the location of juvenile shrimp.

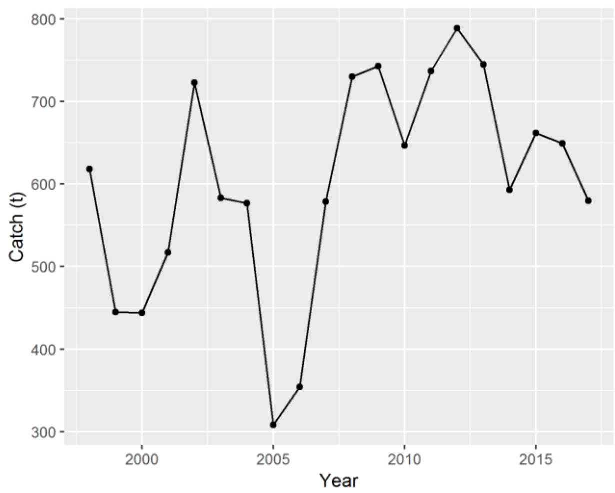


Figure 18: Evolution of *Aristeus antennatus* catch in the GSA 06.

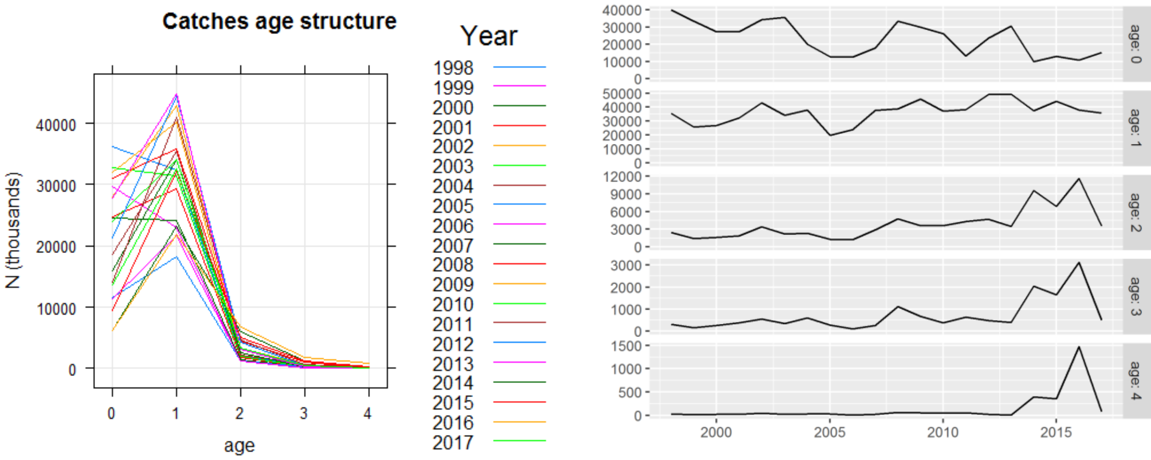


Figure 19: *Aristeus antennatus* age frequency distribution of the total catch in numbers from 1998 to 2017 in GSA 06

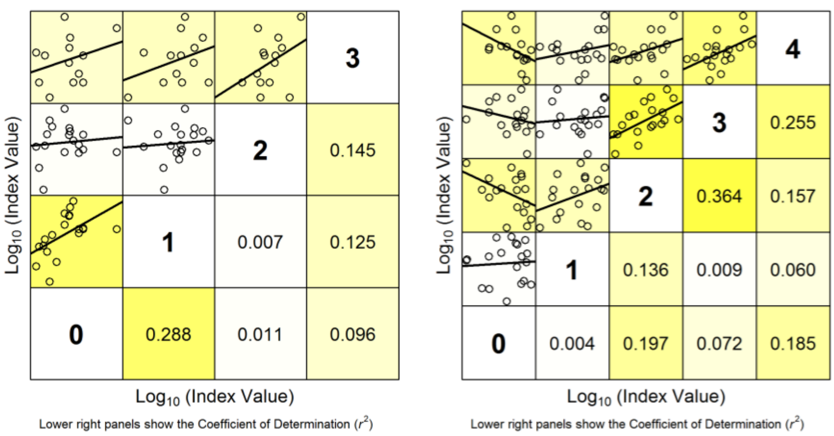


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Figure 20: *Aristeus antennatus* GSA 06. Internal consistency of the tuning fleet (MEDITS Survey).

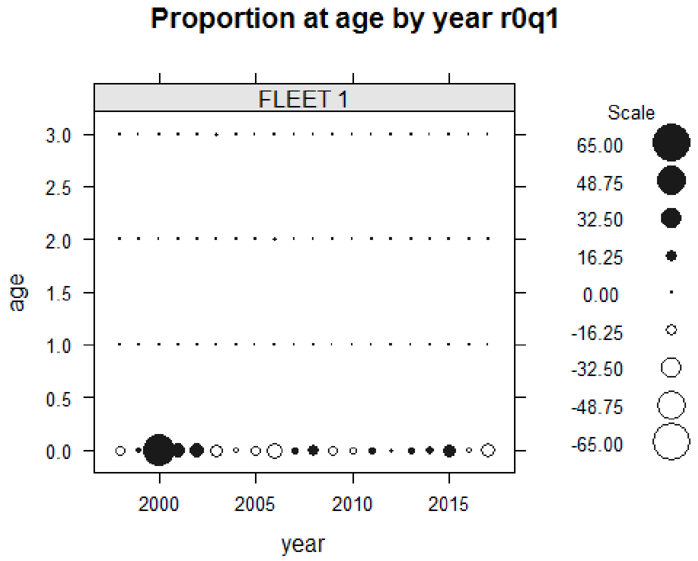


Figure 21: Residual analysis of the best sited XSA' control object

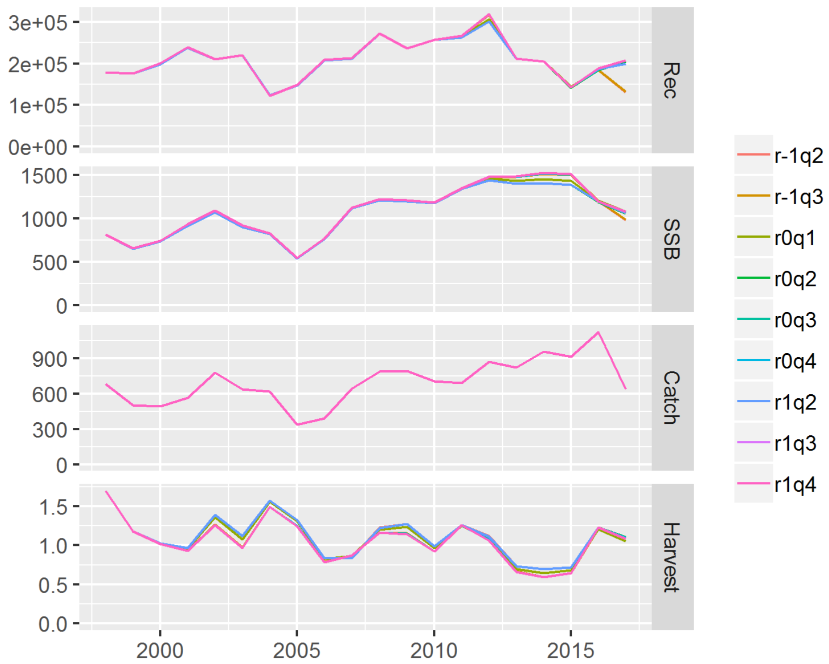


Figure 22: XSA' control object' outputs for a different combination of r at age and the catchability (q) at age.

In addition to the set of control objects, different runs of XSA were carried out in the objective of searching the best trade-off in settings. The shrinkage tested for most of the cases, as it is illustrated in (Figure 23) and (Figure 24), indicates that the XSA run with different settings produce approximately similar estimates of recruitment and SSB.

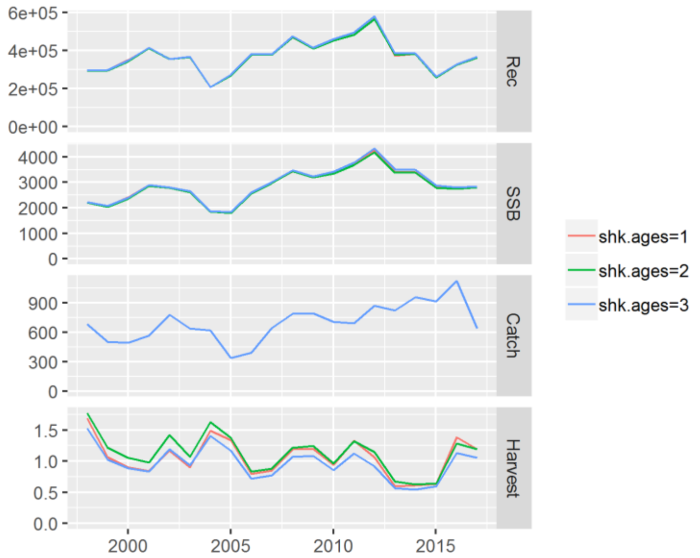
The standard error when shrinking the mean F is set at fse of 2.5, this value is represented by the minimal level of residuals. The number of years used for the shrinkage to the mean (shk.ages) is equal to 3 years.

It's important to highlight that this control object was maintained over the remaining assessment using different methods of natural mortality estimation, mentionned above to avoid creating uncertainties related to the change of the mentioned settings.

III.1.2.1. Retrospective Analysis

The retrospective analysis is an important diagnostic which allows investigating how the estimated values vary over the time series and to ensure a kind of robustness to the final analysis. The results obtained running these types of control with a variety of values of natural mortality are illustrated in (Figure 25).

The outputs of this analysis indicate that the historical estimates for the SSB and recruits for 2016 and 2015 present an overestimation compared to the actual estimations. These can affect significantly the fishing mortality rates for the corresponding years. In fact, it appears that the analysis gives consistent results concerning the last five years (year 5) where the SSB appears more realistic. In general, it seems that there is an insignificant difference in the results of each method used except for the last assessment which assumes a steady decreasing shape for the SSB.



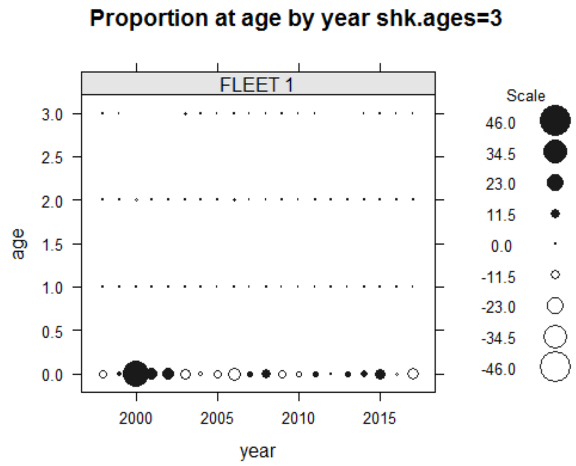


Figure 23: XSA' outputs for different shrinkage scenarios

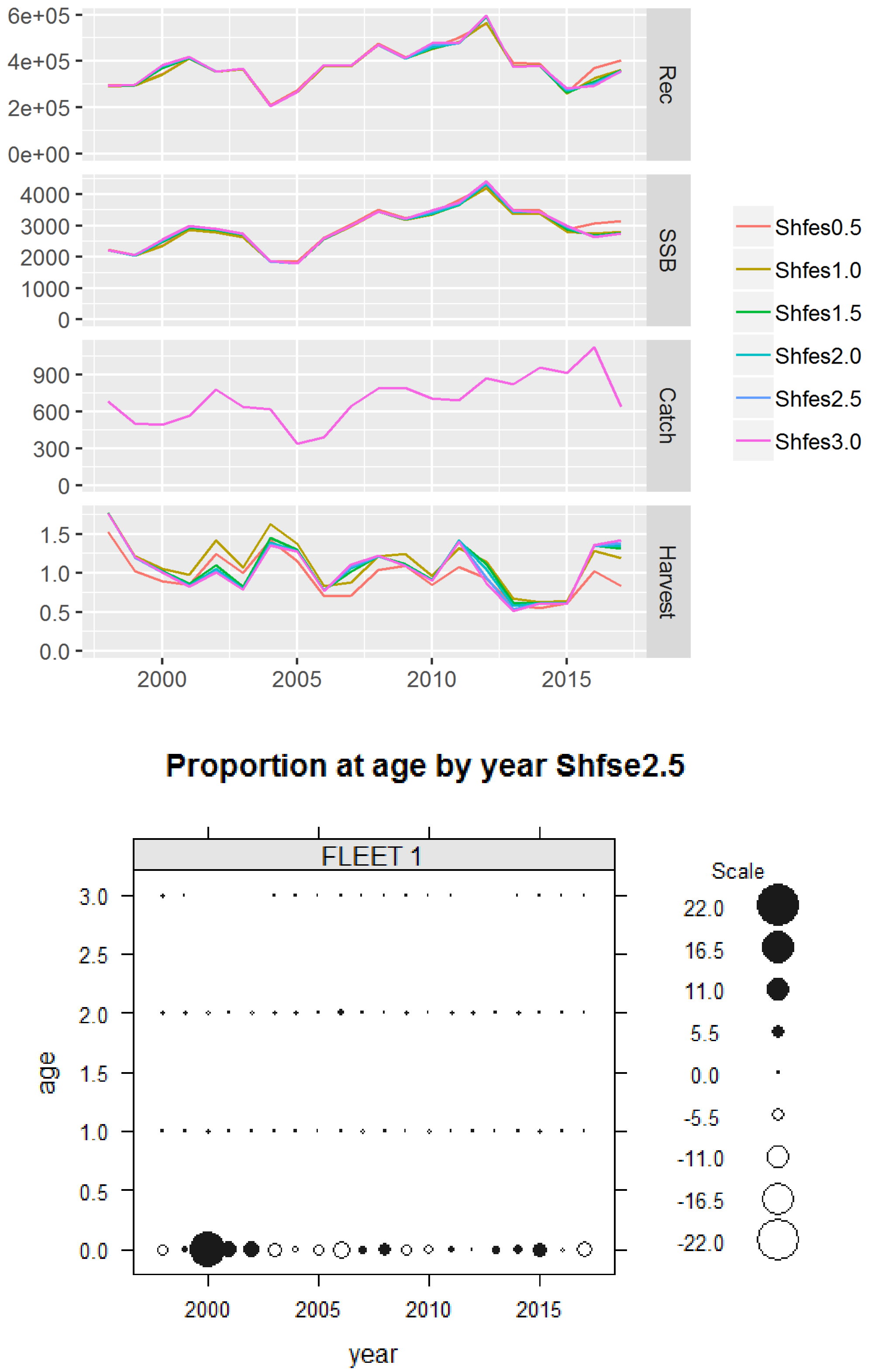


Figure 24: XSA' outputs by different residuals of tuning fleet

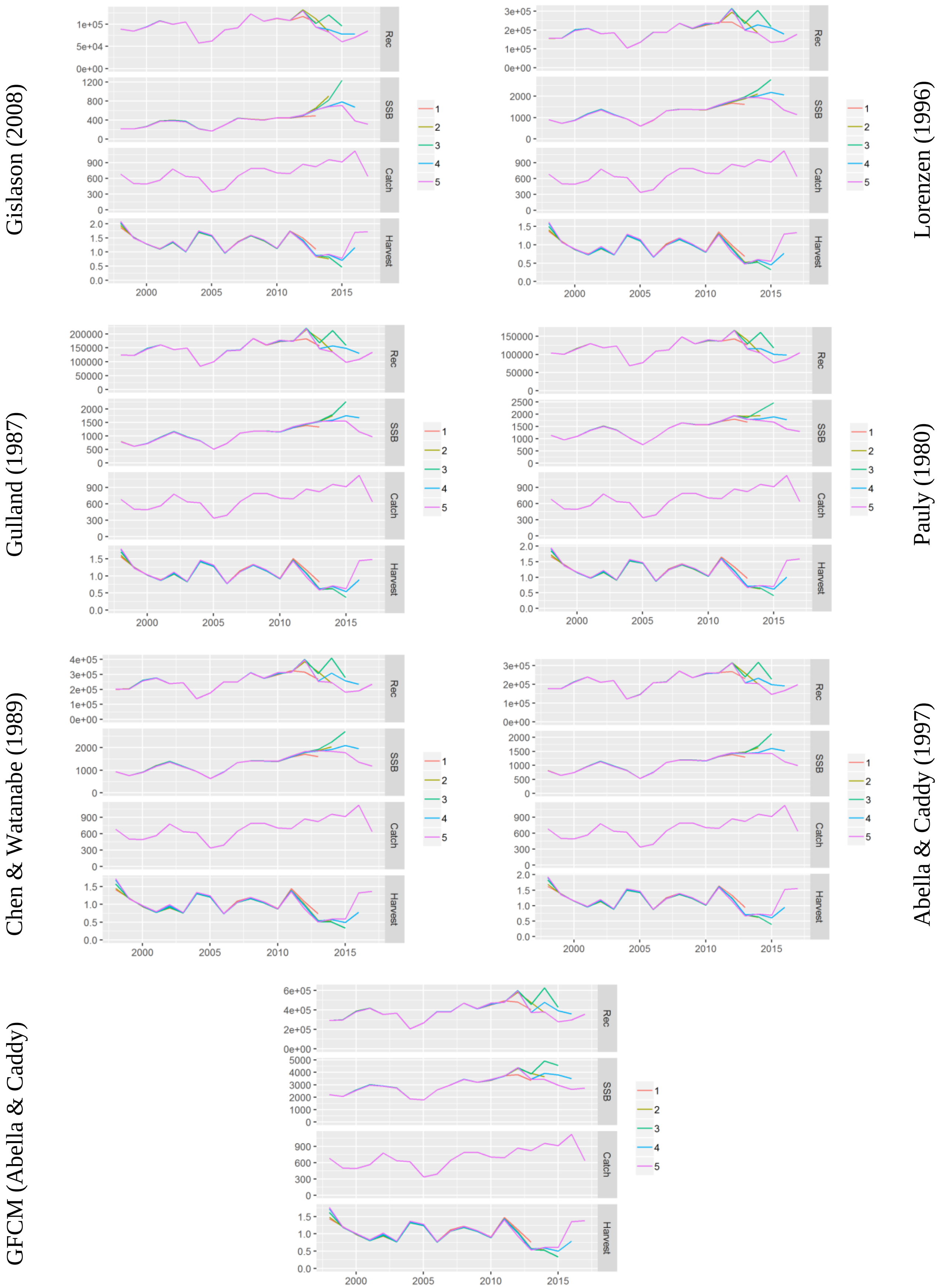


Figure 25: Retrospective analysis of the blue and red shrimp in GSA 06 with diverse values of (M).

III.1.3. FINAL RESULTS COMPARISON AND REFERENCE POINTS

The fishing mortality ($Fbar_{0-3}$) obtained with changeable assessment as shown in Figure 26, indicates fluctuations over the years with an average value ranging between 0,4 and 2/year. From 2011 a slight trend is noticeable, which keeps the same value from 2012 to 2015, then increase significantly from the following year to remain in a very high value over the past two years. The values obtained from the Gislaon model presents the highest value and the Lorenzen model gives the insignificant one.

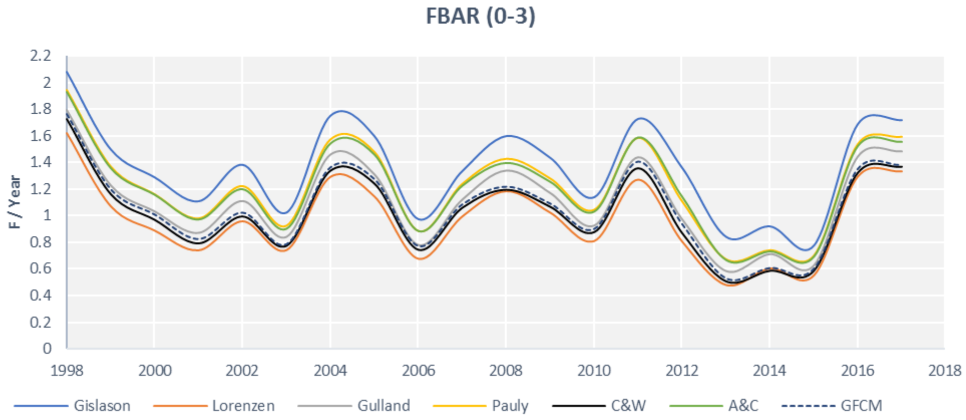


Figure 26: Mean fishing mortality comparison using different values of (M)

In this context, the recruitment trends resulting from the distinct assessments (Figure 27) evaluate inversely concerning the average fishing mortality. The greater value is observed for the vectorial mortality estimated by the ProdBiom and used for the stock assessment in 2017. The Gislason model represents minor recruitment over all the rest of the models.

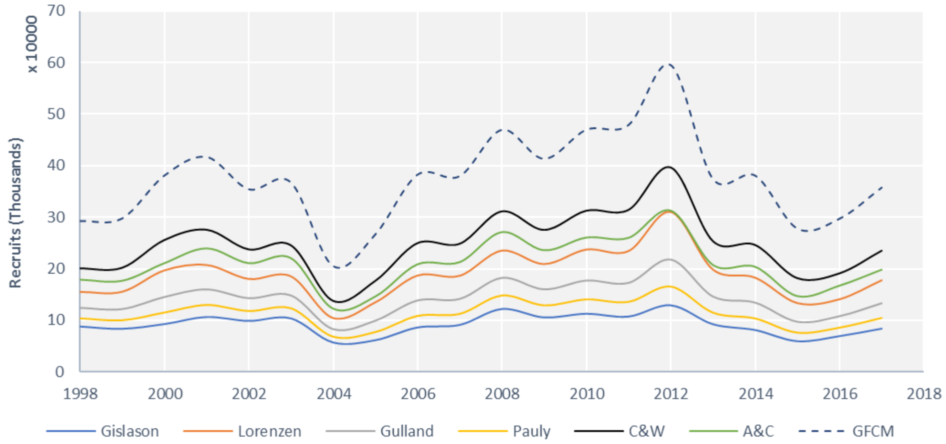


Figure 27: Recruitment (R) trends with different values of natural mortality (M)

The same tendency is kept for the spawning stock biomass where it's clearly noticed the importance rate of the SSB using the natural mortality calculated with ProdBiom. For that, the red shrimp stock presents, in general, an increasing tendency within the increase of the natural mortality value.

The age-dependent methods applied to estimate the natural mortality seem to give plausible results for the Stock Spawning Biomass (SSB) and the recruitment (R)(Figure 28). As a result, the explanation of the usefulness of considering the changes that could happen to the stocks within their life.

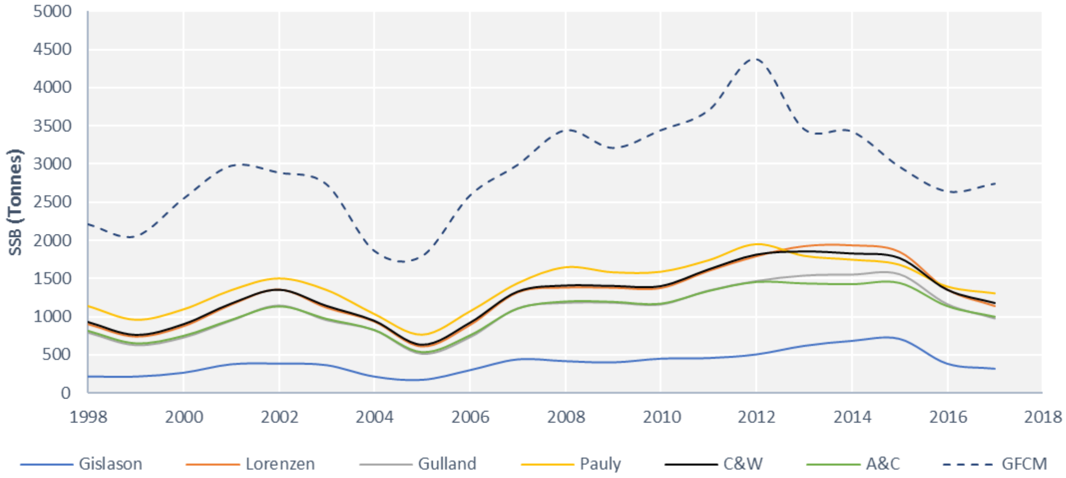


Figure 28: Spawning stock biomass (SSB) from XSA runs with changing (M)

REFERENCE POINTS

The estimation of the reference points using different values of natural mortality (M) calculated with several methods, is shown in the table below (

Table 6). The analysis of the different fishing mortalities presents an **Overfishing status** of the red shrimp' stock.

The ratio between the current fishing intensity and the $F_{0.1}$ presents an extremely high value compared with the conventional rates [1.66]. The Abella & Caddy' vectorial method and Gislason M scalar method, give the highest results for the ratio $F_{curr}/F_{0.1}$, this might be considered as an overestimated result but at the same time could be set as a good starting point when applying the precautionary approach. Meanwhile, the results differ noticeably among the models used to estimate the natural mortality rates and then, lead to distinct assumptions about the assessment advice.

In addition, the exploitation rate expressed by the ratio F/F_{MSY} indicates an unsustainability situation for all the assessment but especially for the last scenario that used the ProdBiom' M estimation and gives a very high value.

On the other hand, all the outputs of the outlined models have been applied to run assessments with Beverton & Holt model and Ricker model. If models only differ in their fixed effects, then the *Akaike information criterion* (AIC) can be applied to determine evidence in favour of one model over another (Wilberg et *al*., 2009).

The *Bayesian information criterion* (BIC) is run over the same conditions as the AIC. The comparison demonstrates that the models fitted well with the Gislason and Pauly methods for the scaler M and with Abella & Caddy method for the vectorial M.

Table 6: Different values of reference point obtained using distinct values of (M)

Parameters \ Method		Gislason	Lorenzen	Gulland	Pauly	Chen & Watanabe	Abella & Caddy	M used in stock assessment (2017)
$F_{0.1}$		0.23	0.53	0.39	0.30	0.38	0.25	0.33
F_{curr}		1.39	1.06	1.19	1.28	1.09	1.26	1.11
F_{msy}		1.19	4.60	0.95	0.37	0.83	0.52	0.28
$F_{curr}/ F_{0.1}$		**6.06**	**2.00**	**3.05**	**4.26**	**2.87**	**5.03**	**3.36**
F_{curr}/ F_{msy}		**1.16**	0.23	**1.25**	**3.45**	**1.31**	**2.42**	**3.96**
Overfishing Range of the ratio $F_{curr}/ F_{0.1}$	<= 1.33							
	[1.33-1.66]							
	>=1.66							
AIC	Ricker	**-55.001**	**-46.800**	**-48.108**	-52.073	**-48.462**	**-49.487**	-69.108
	Beverton & Holt	-47.840	-46.372	-47.270	**-52.154**	-48.323	-49.182	**-69.124**
BIC	Ricker	**-53.009**	**-44.809**	-46.116	-50.082	**-46.470**	**-47.495**	-67.116
	Beverton & Holt	-45.849	-44.381	**-45.279**	**-50.163**	-46.331	-47.191	**-67.133**

Graphically, the analysis of the yield per recruits over the different scenarios shows an augmenting trend which manifests by significant productivity when the decrease occurs in scalar natural mortality (Figure 29).

For M vector values, the Abella & Caddy method provides the highest level of yield per recruit, followed by the Chen & Watanabe scenario. The value of M used in the GFCM assessment' gives a higher yield than the previously mentioned scenario since the estimate of the natural mortality was carried out by ProdBiom (Table 6).

Overall, with regards to the fishing mortalities, it's clearly evident that the situation of the red shrimp stock' in the GSA06, presents an **overfishing status**. The current fishing mortalities for all the scenarios are on the right side of the reference fishing mortality point $F_{0.1}$ and present substantially high values comparing with it.

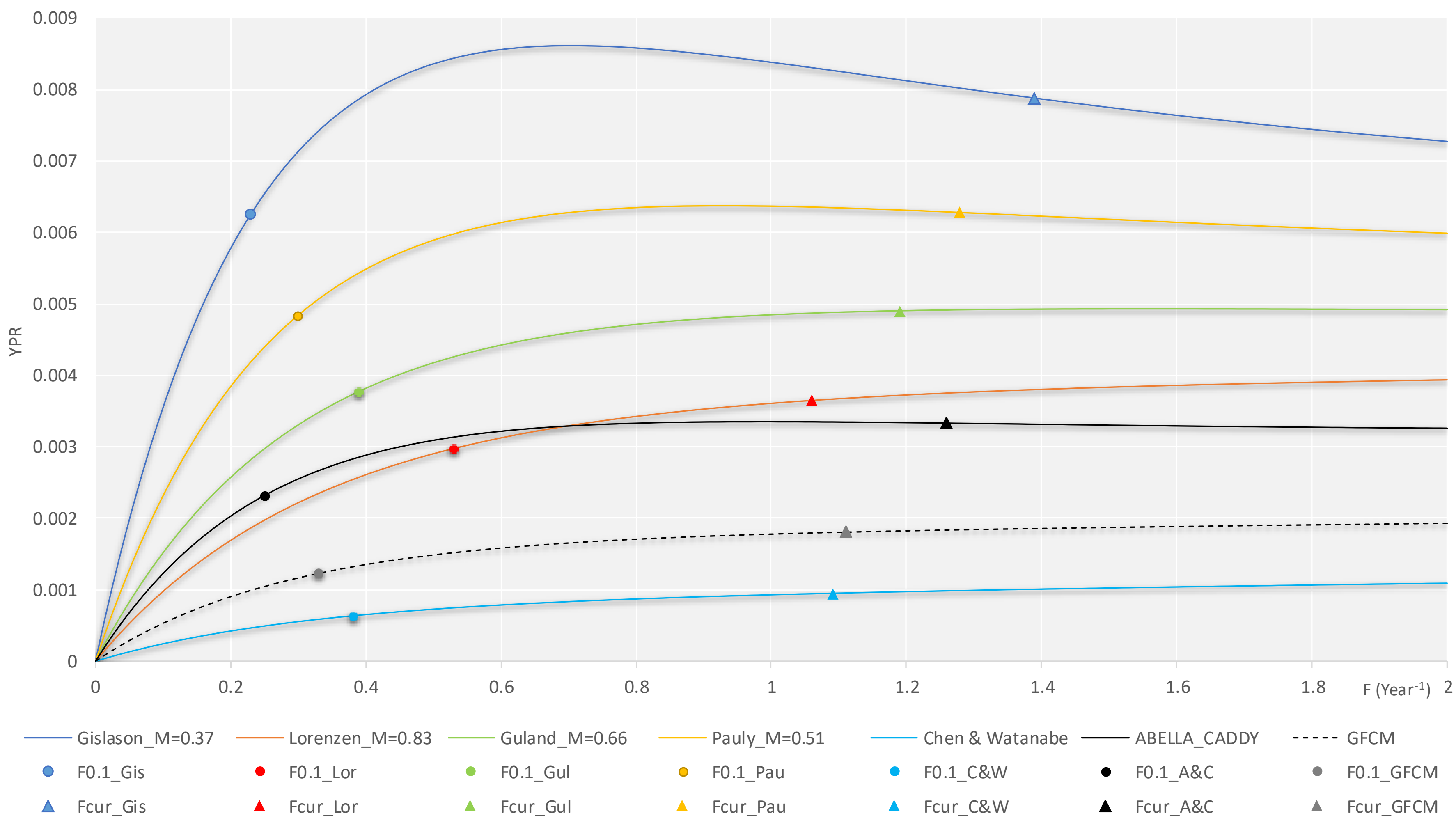


Figure 29: Red Shrimp Stock in GSA 06 Yield per Recruit function over a range of fishing mortality (F) for different scenarios based on different (M)

In contrast, the analysis of the SSB and R relationship exemplified in (Figure 30) clearly defines the importance of the input parameters regarding the distribution of recruits in relation with the SSB values. Here it is shown that all the estimates with each value of mortality present a rapid increase in recruitment while the SSB increases and vice-versa. Obtaining a suitable model, in this case, seems to be in favour of the assessment using natural mortality calculated with the ProdBiom method. The other methods express, more or less, a good relationship between the parental stock and recruits like the Chen & Watanabe method.

Besides, it's clear that age-independent methods as well as the model of Gislason, Lorenzen and Pauly give more or less weak combinations and may lead to erroneous estimates on the stock' state. The age-dependent methods like the ProdBiom are more appropriate and express a good relationship with regards to the parental stock and recruits.

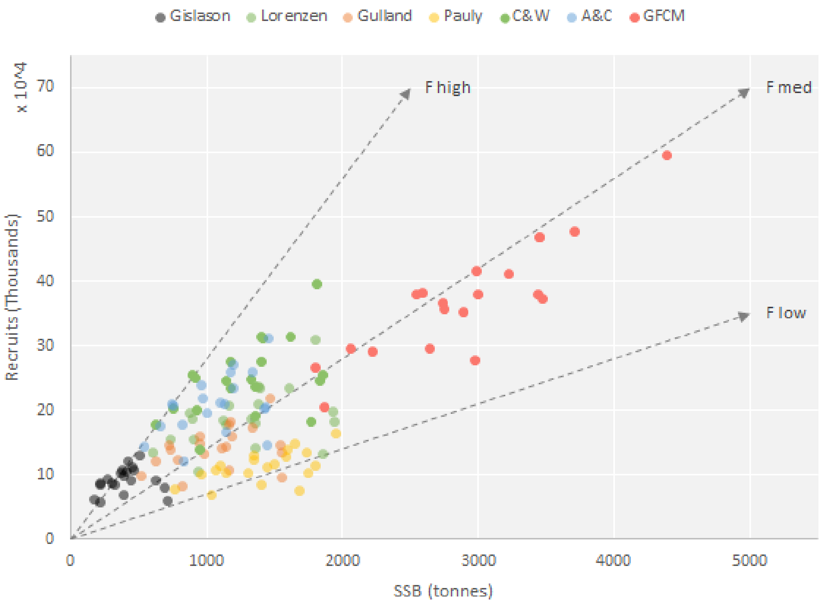
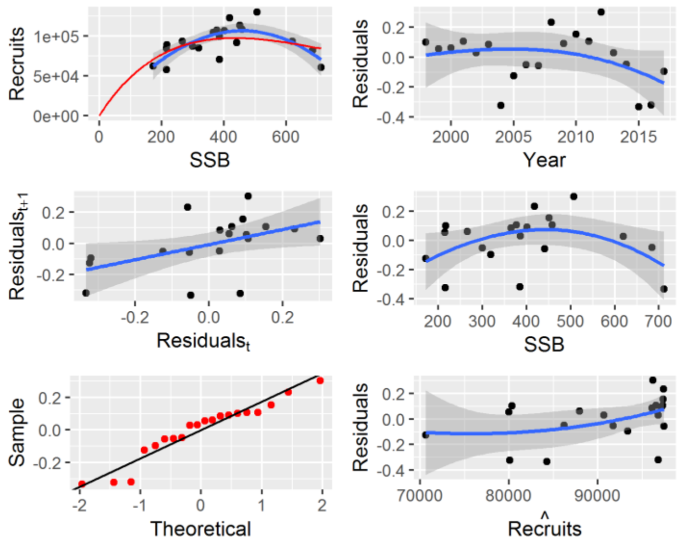


Figure 30: Spawning Stock Biomass and Recruitment of the different assessments of the red shrimp

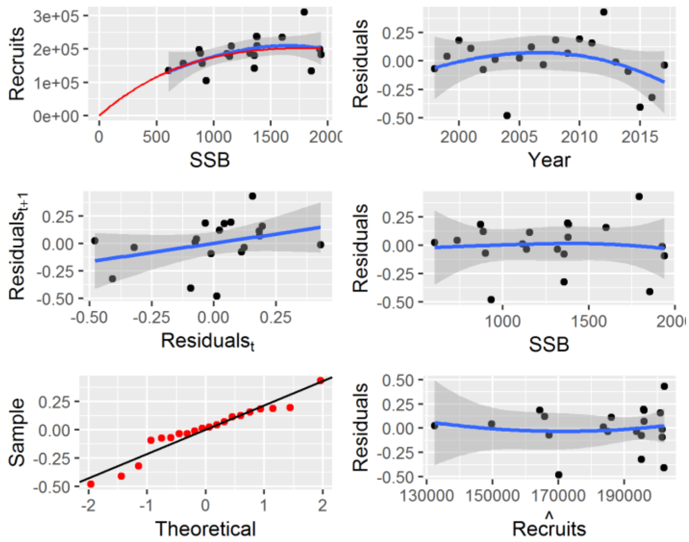
To verify this theory, the quality of the correlation between the SSB and R was verified statistically by the application of the Ricker model (Figure 31) which give an image of the residual analysis.

The results express that all the age-dependent methods present a random distribution of the residuals and this could explain the existence of a good positive correlation between the recruits and the parental stock but also it demonstrates that the empiric methods except Pauly method, present insufficient evidence of correlation. This is very visible with the residuals analysis which demonstrates that there is an increasing variance for the recruits against residuals resulting from the methods Gislason, Lorenzen, and Gulland.

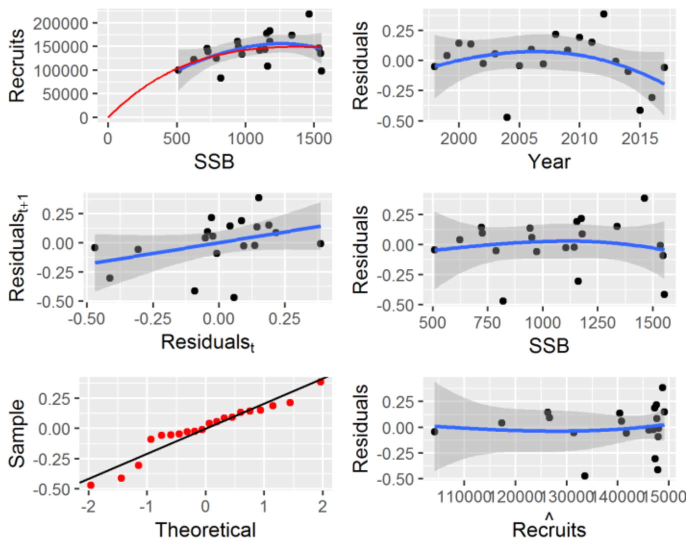
(a)



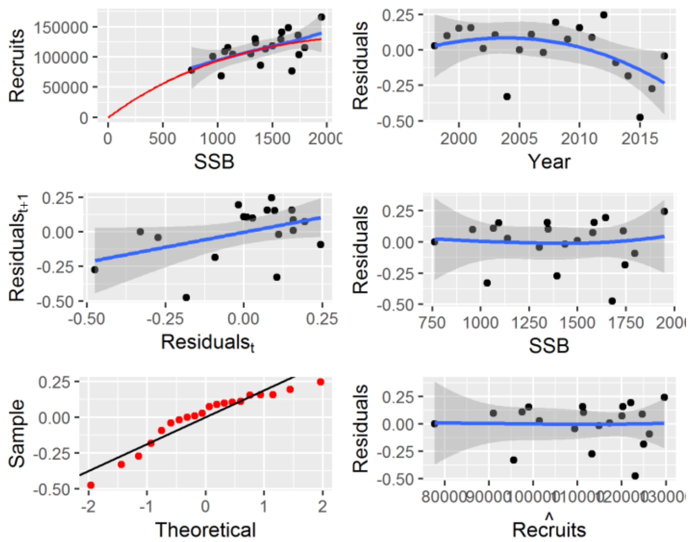
Gislason (2008)



Lorenzen (1996)



Gulland (1987)



Pauly (1980)

(b)

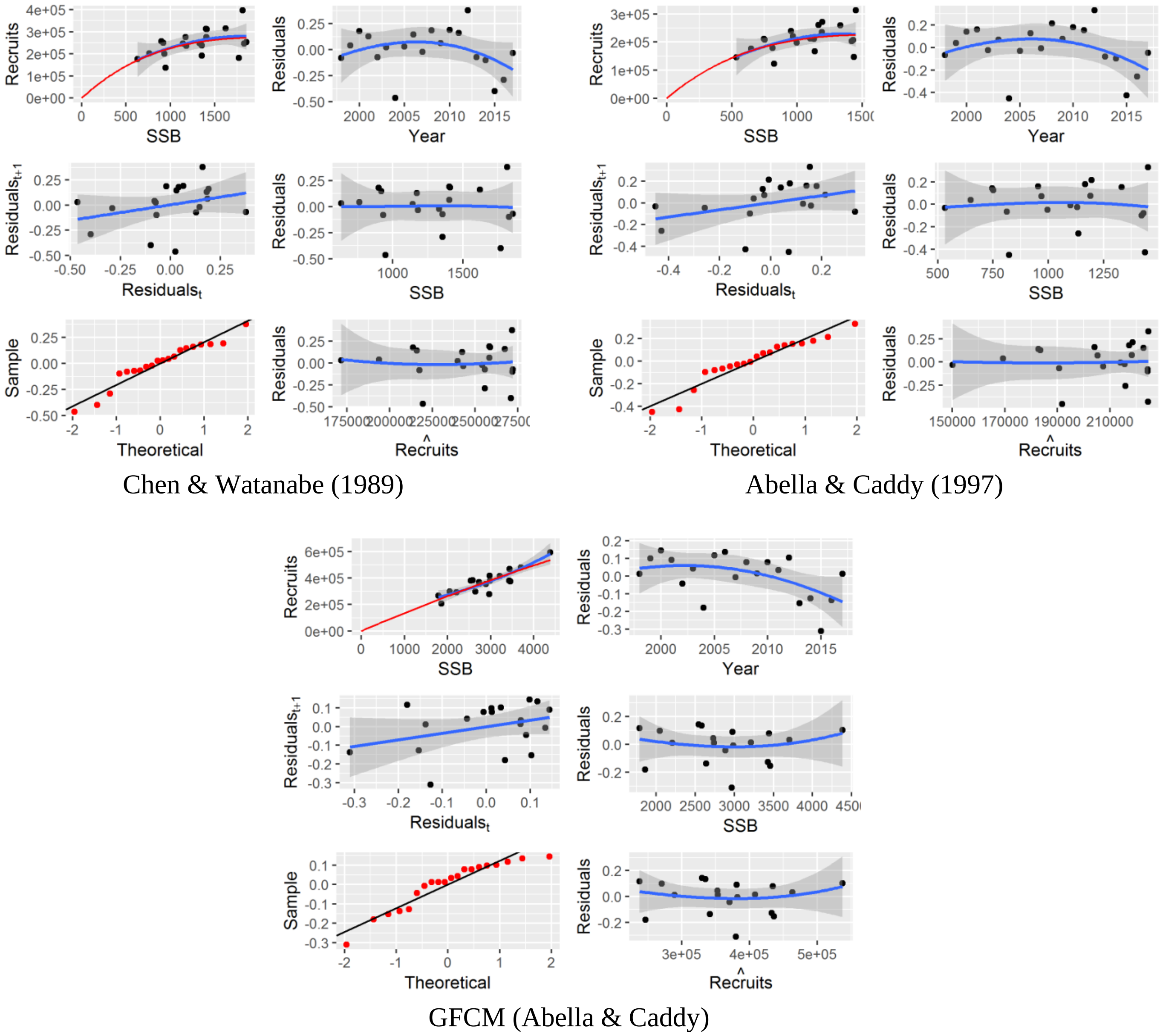


Figure 31: Residuals simulations scenarios with positive correlation for R-SSB relationship

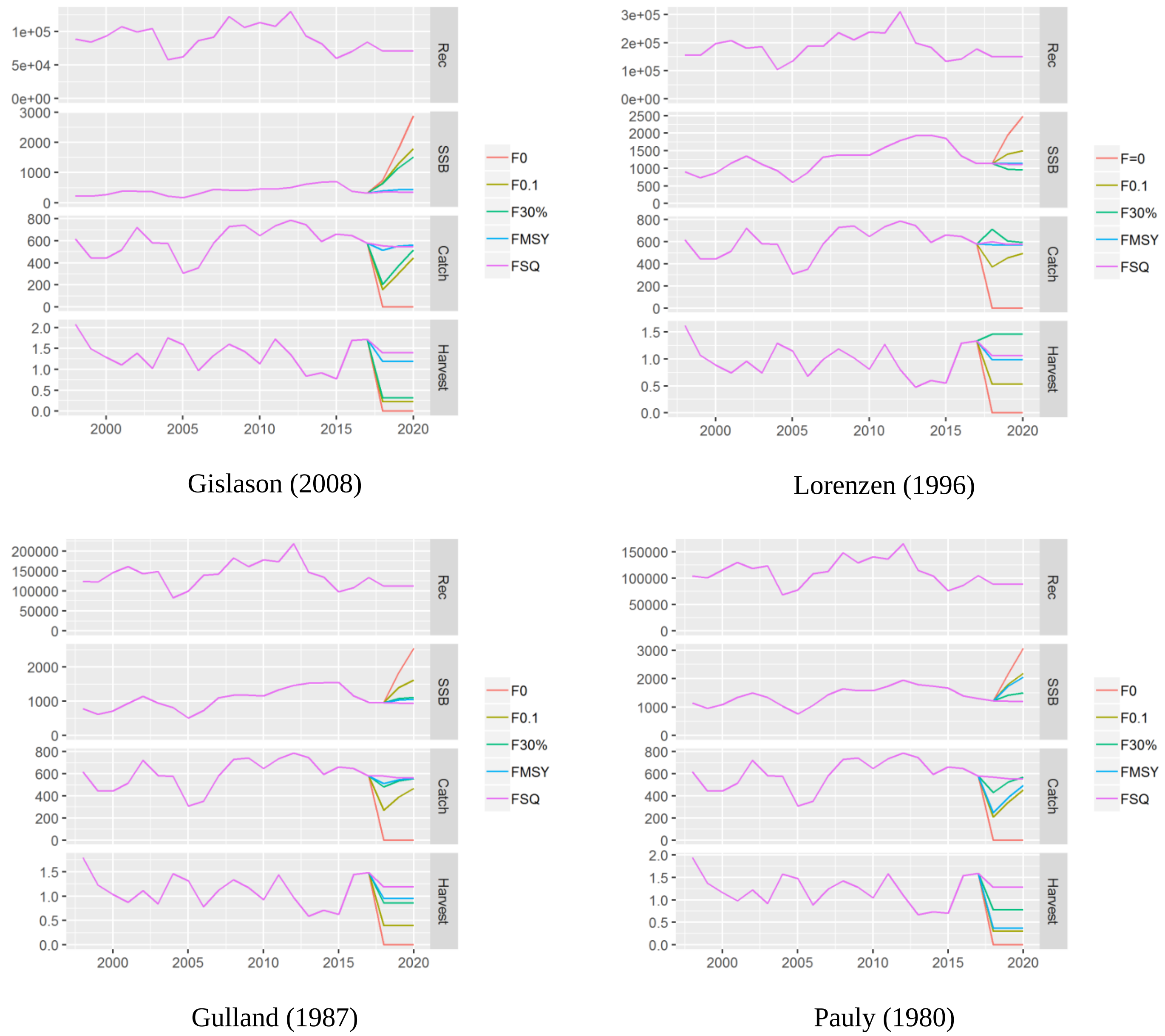
(a) Ricker model application using natural mortalities estimated by age-independent methods

(b) Ricker model application using natural mortalities estimated by age-independent methods

III.1.4. SHORT TERM FORECASTING RESULTS

The short-term forecasting reveals the importance of setting the $F_{0.1}$ as a reference point. All the scenarios tested for the different assessments show a consistent increase of the catch when applying the reduction of current fishing mortality towards the reference point (Figure 32: Forecasting results of the different simulations with natural mortality).

(a)



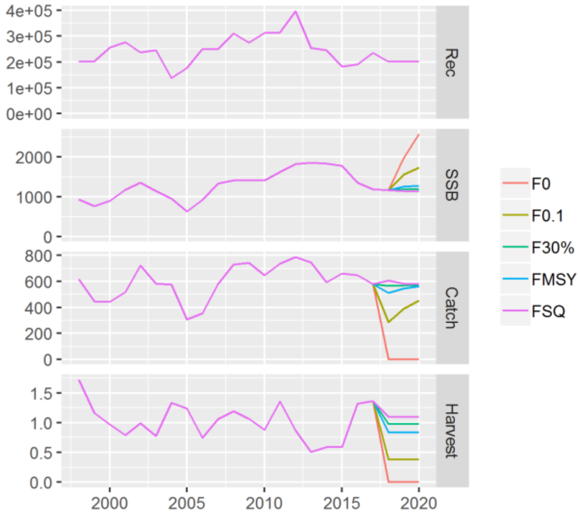
Gislason (2008)

Lorenzen (1996)

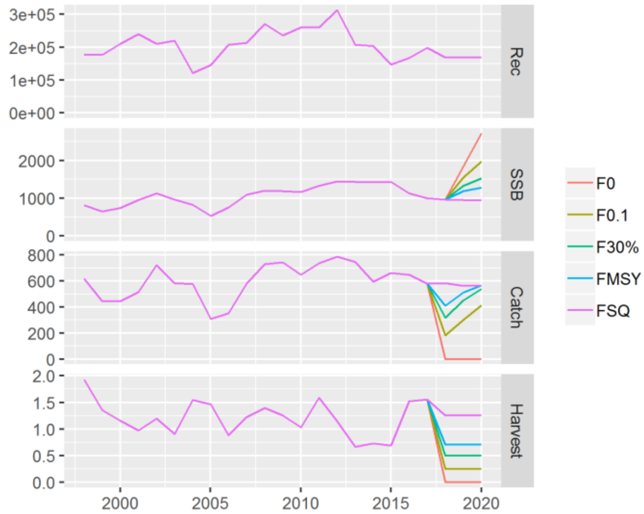
Gulland (1987)

Pauly (1980)

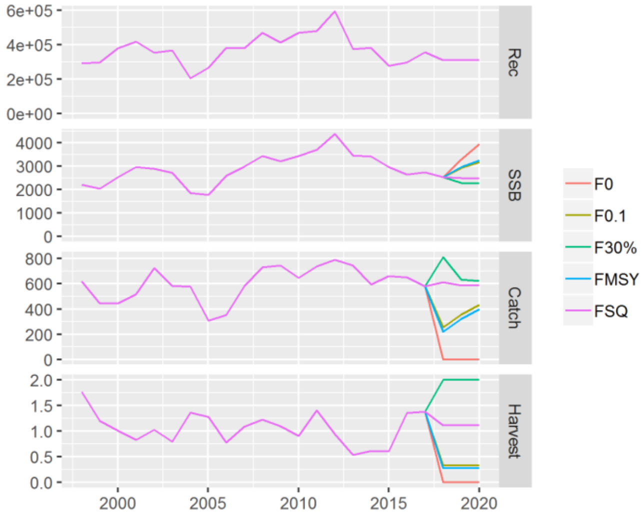
(b)



Chen & Watanabe (1989)



Abella & Caddy (1997)



GFCM (Abella & Caddy)

Figure 32: Forecasting results of the different simulations with natural mortality

III.2. THE RED MULLET (*Mullus barbatus* "MUT")

RESULTS

III.2.1. NATURAL MORTALITY RESULTS

The same procedure as in the red bleu shrimp will be undertaken for this species. The results of the red mullet' natural mortality parameters estimation are indicated in (Table 7), (Table 8) and (Figure 33).

Table 7: Annual Natural Mortality (M) Scalar values

Method	Gislason	Lorenzen	Gulland	Pauly
M ($year^{-1}$)	0.40	0.55	0.67	0.59

Table 8: Annual Natural Mortality (M) at age

Method / Age	Chen & Watanabe M ($year^{-1}$)	Abella & Caddy M ($year^{-1}$)	M used in stock assessment (2017) M ($year^{-1}$)
0	1.73	1.23	1.23
I	1.06	0.51	0.41
II	0.66	0.37	0.28
III	0.52	0.31	0.22
IV	0.45	0.28	0.21
V	0.41	0.27	0.20

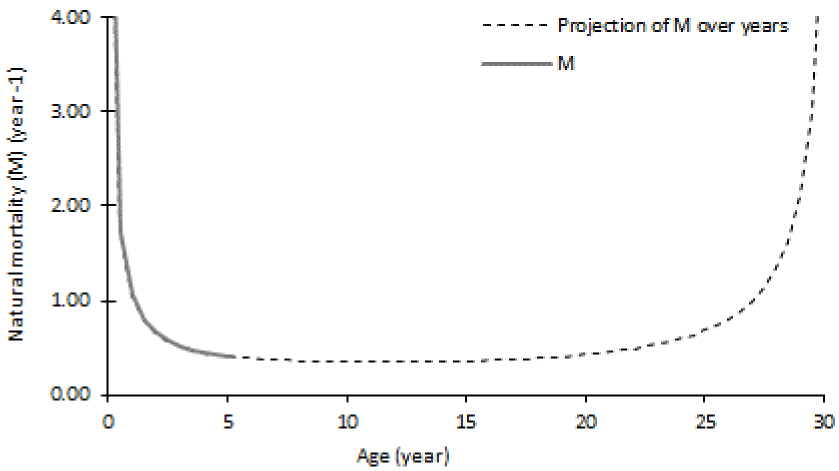


Figure 33: The bathtub U-shaped to estimate the age-dependent instantaneous natural mortality (M) of *Mullus barbatus* in GSA 06.

For the application of ProdBiom Program it has been chosen asymptotic mortality (Ma) which gave the lowest quadratic differences, the calculation was done on excel using the solver. (Figure 34) illustrates diverse curves obtained using different values of (Ma) where the (Ma) corresponding to the value of 0.19 has been chosen to continue the calculation.

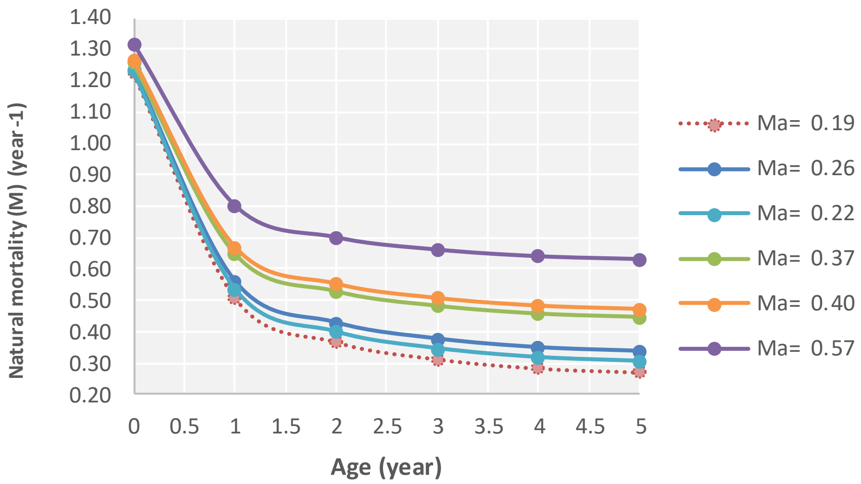


Figure 34: Different values of (M) obtained using the ProdBiom model with several asymptotic mortalities (Ma) on *Mullus barbatus* of the GSA 06.

III.2.2. The XSA results

The historical data analysed for the red mullet (Figure 35) began in 2004 where three periods of the evolution of commercial catches were recorded. The first period starts from 2004 to 2006 when catches present a rising trend. The next phase is characterized by a downward trend from 2006 to 2011 probably due to the decline of the total trawl fleet in GSA 06, from 810 boats in 1998 to 424 boats in 2016, reported by (García Rodríguez, et *al.*, 2017). The final period is considered by a slight increase that will not persist for the last year 2017.

The desegregation of the catch curve with age groups leads to identify the representativity of each age in landings (Figure 36). The age groups I and II are the most present so the analysis and the average fishing mortality will be focused on them despite the weakness of the coeficient of determination calculated for each group. This composition is explained by the enforcement of the new mesh type in 2010 (40 mm square or alternatively 50 mm diamond).

The Residual analysis has been carried out to select the best XSA' control object. The results are in favour of **r0q1**(Figure 38) as it presents the highest harvest compared to other settings and may conduct to avoid a sub estimation of fishing mortality (Figure 39). This seeing will be defined as a standard for all the assessment using different values of natural mortality (M).

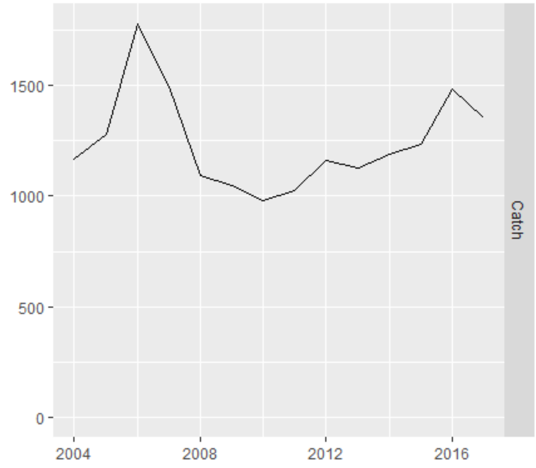


Figure 35: Evolution of the capture of Mullus barbatus in GSA 06.

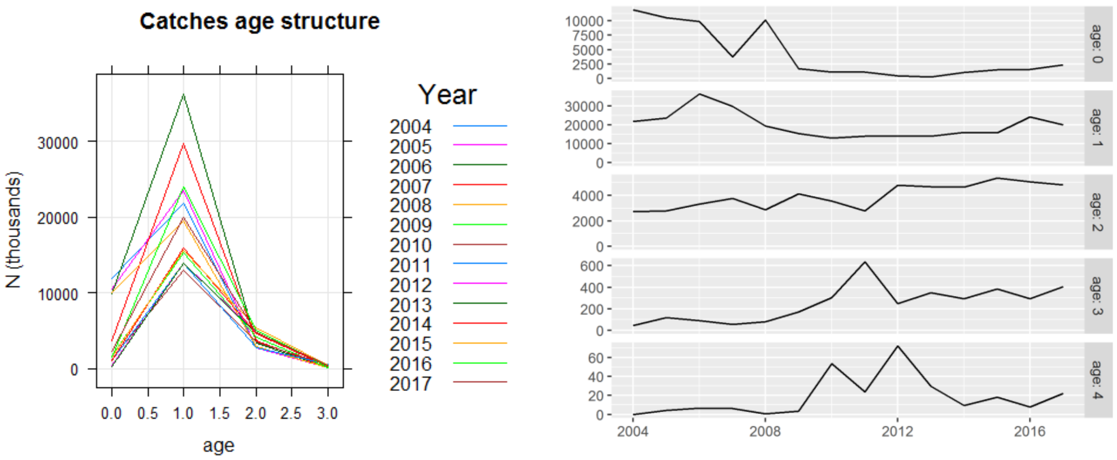


Figure 36: *Mullus barbatus* catches-age structure from 2004 to 2017 in GSA 06

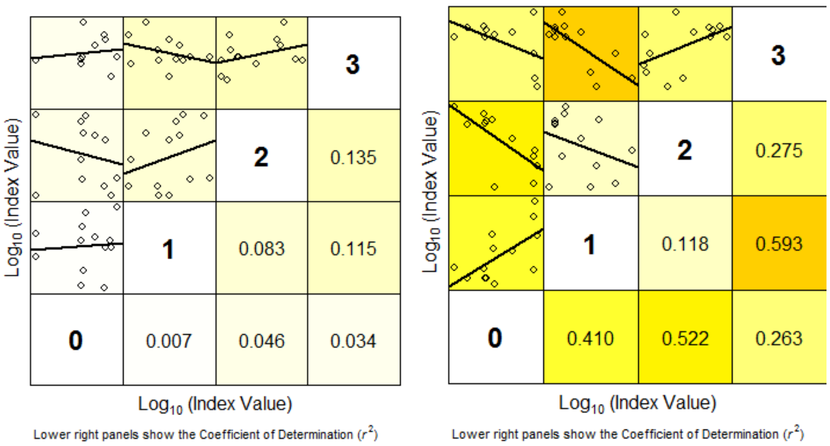


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Figure 37: *Mullus barbatus* GSA 06. Internal consistency of the tuning fleet (MEDITS Survey).

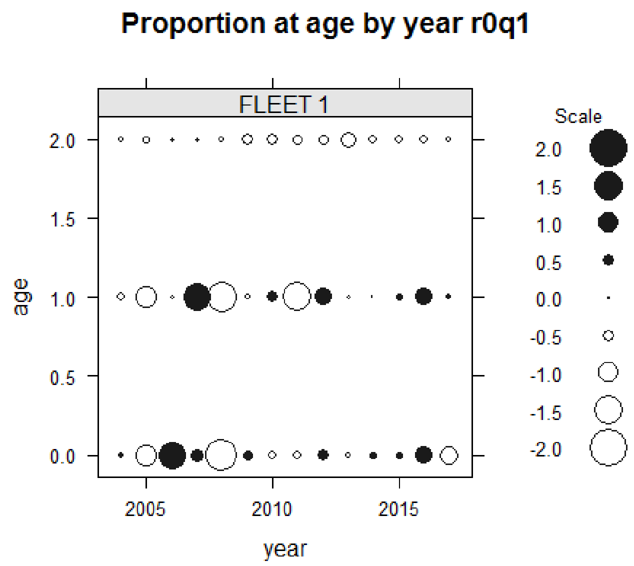


Figure 38: Residual analysis of the best sited XSA' control object

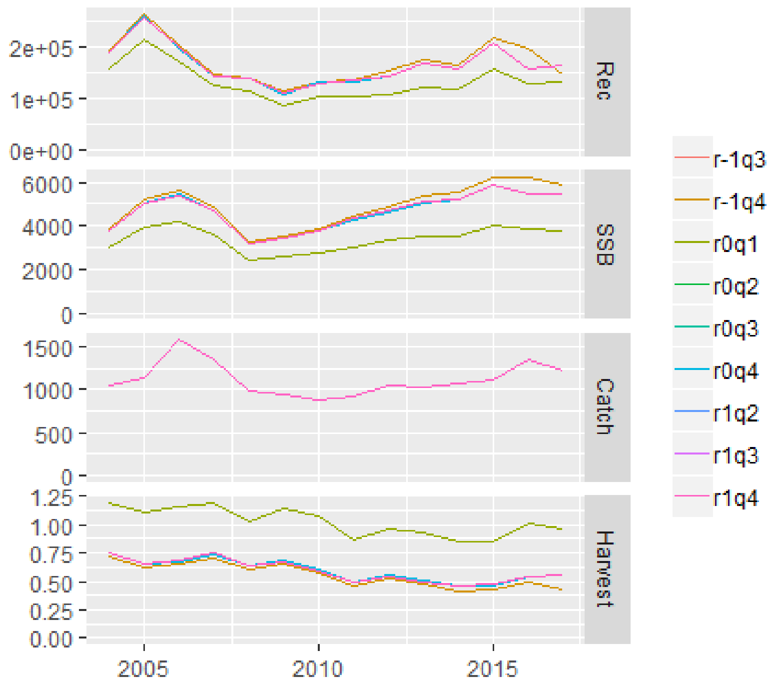


Figure 39: XSA' control object outputs for a different combination of r and catchability (q) at age.

On the other hand, several shrinkages have been tested (Figure 40) where similar tendencies have been observed. For this, the residual analysis reveals that the best choice is to shrink by three years (shk.ages=3).

The set of the standard error when shrinking the mean F has also been checked and presents the same shape but the minimum residuals' results are in favour of an (fse) of 2.5 (Figure 41).

However, changing the natural mortality values, the previously mentioned parameters will be maintained to perform all assessments with XSA for the red mullet of the GSA 06.

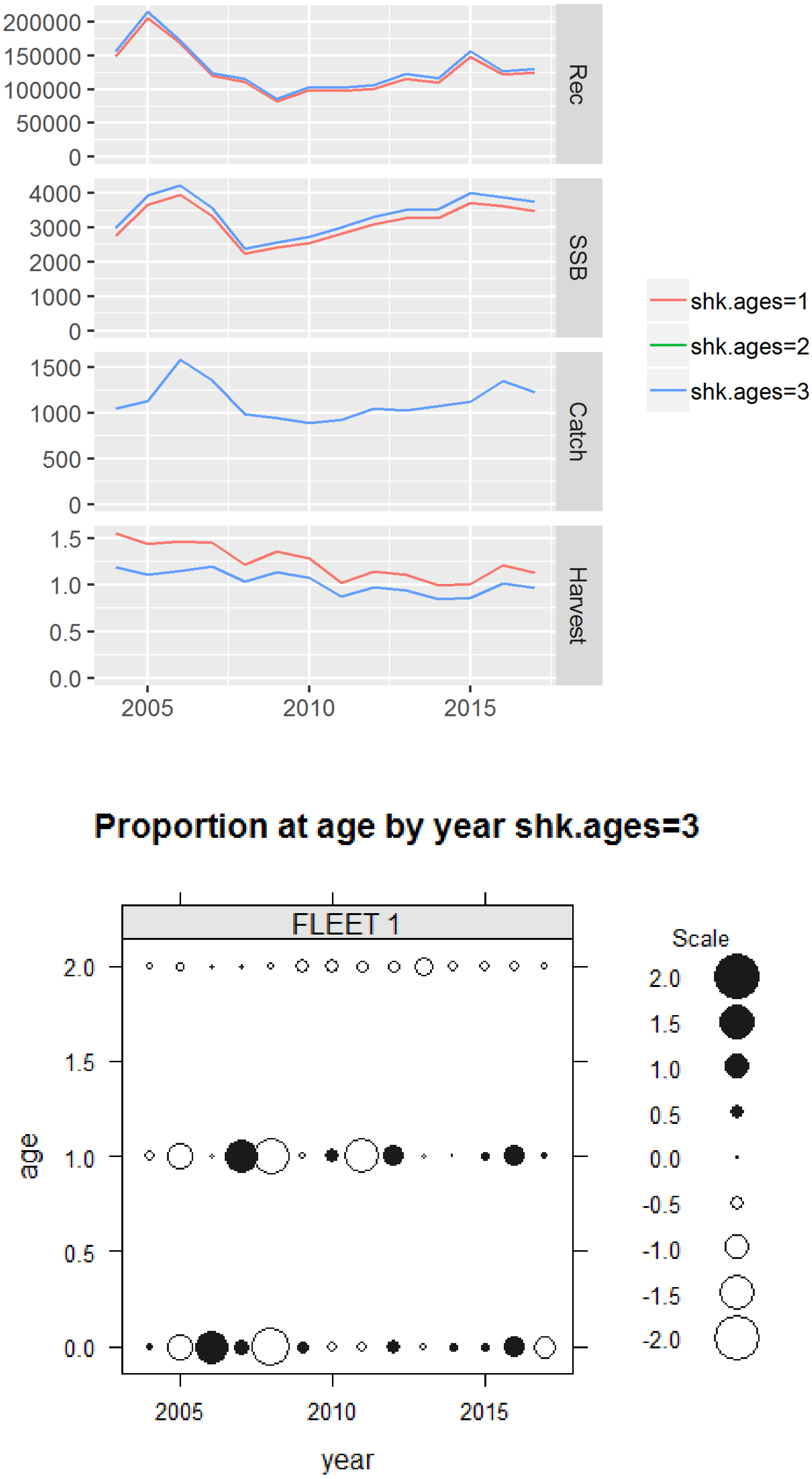
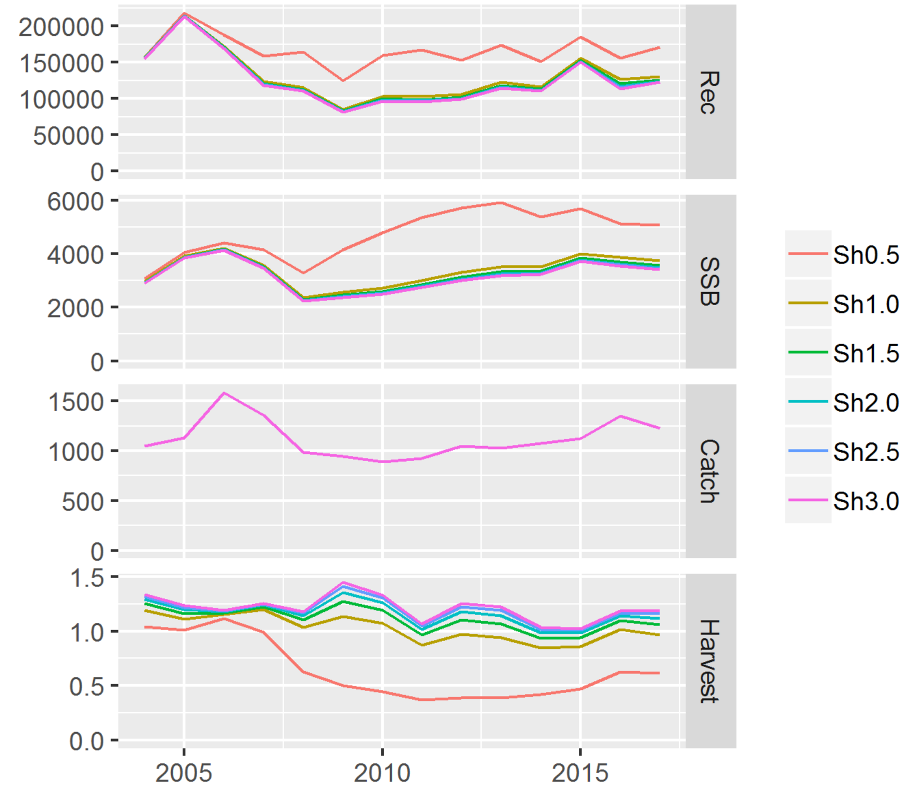


Figure 40: XSA' outputs for different shrinkage scenarios



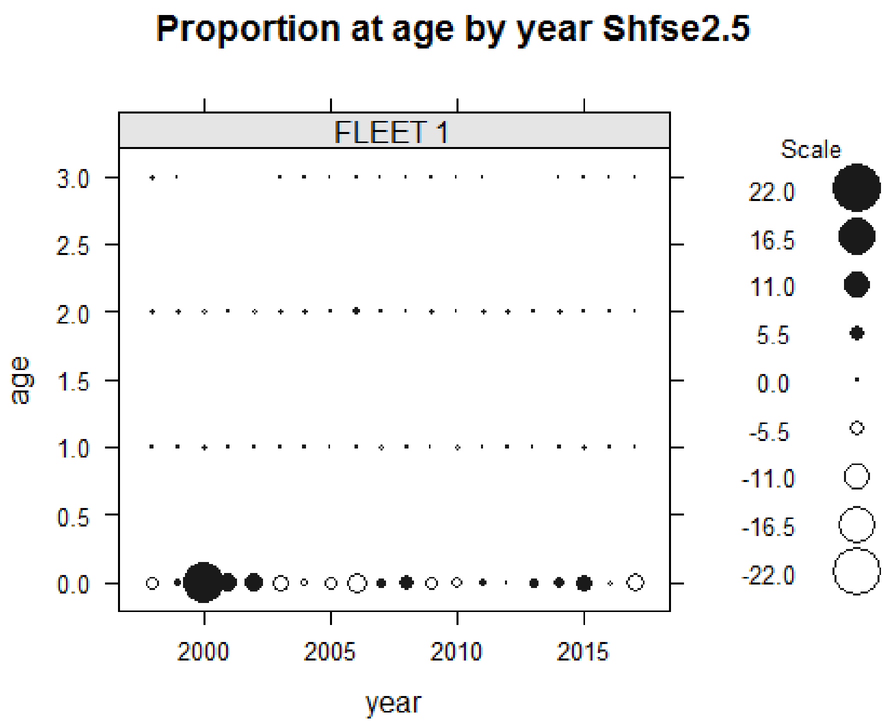
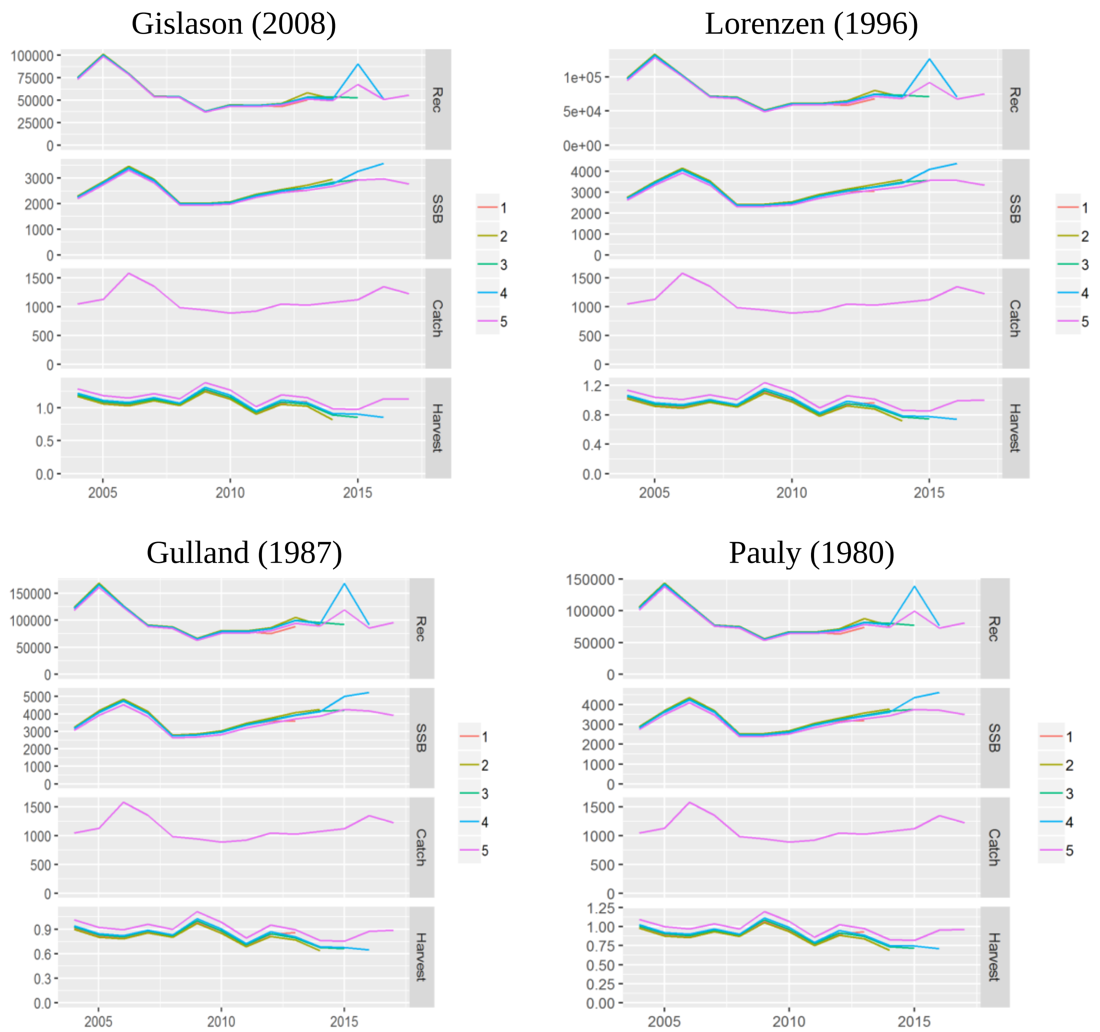


Figure 41: XSA' outputs by different residuals of tuning fleet

III.2.2.1. Retrospective Analysis

For red mullet, a retrospective analysis was performed to verify the average F estimate over several years assuming that catchability is constant for ages. The scenarios are used to attempt and to reveal the existence or not of erroneous estimates for each evaluation. In this case, the use of the same conditions with distinct values of natural mortality (M) seems to lead to similar results and trends for each category of M (scalar or vector). The SSB calculated for the scenario Chen & Watanabe and ProdBiom presents an upward trend for the last years contrary to scenarios with scalar M value which produce a decline of the parental stock from 2015 (Figure 42**)**.



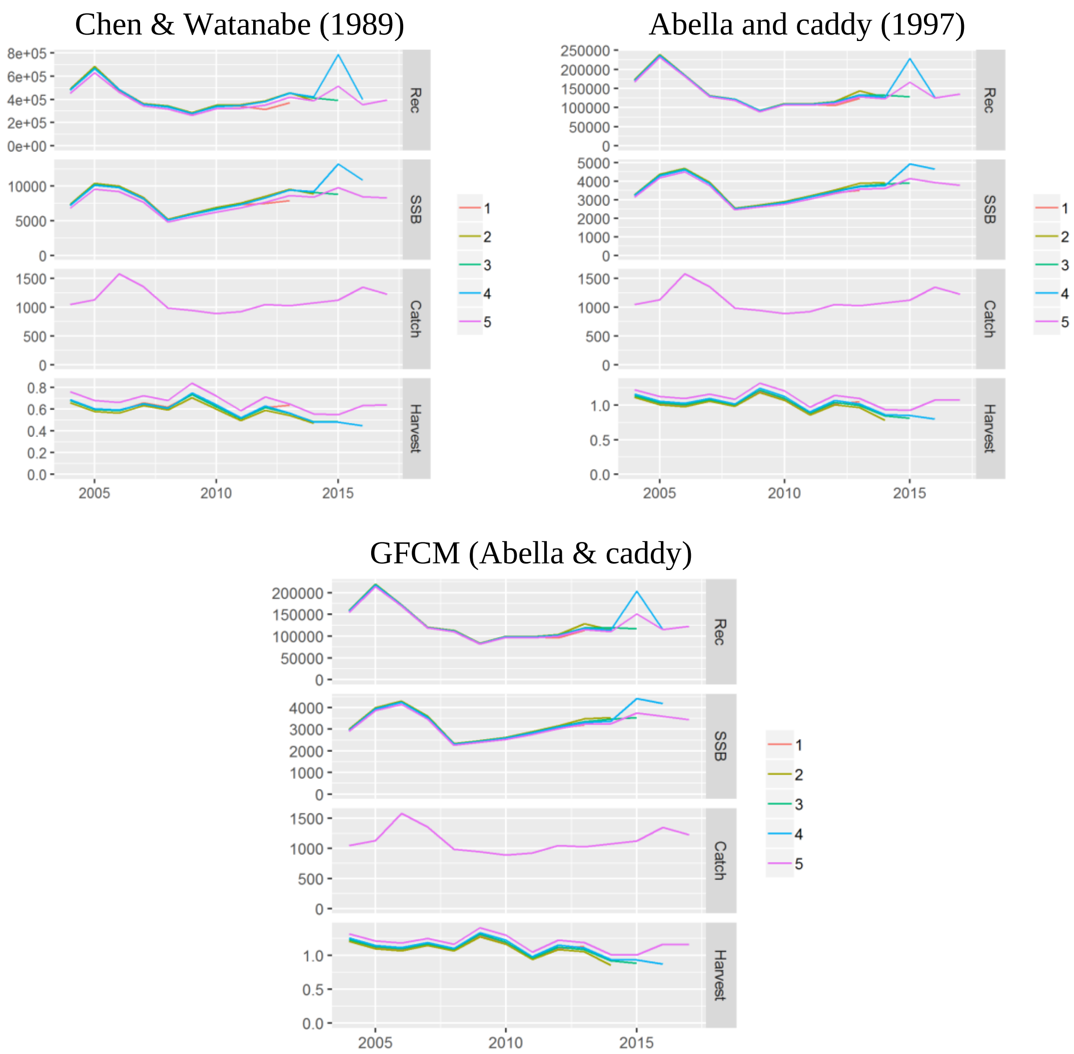


Figure 42: Retrospective analysis of the red mullet in the GSA 06 with different values of M.

III.2.3. FINAL RESULTS COMPARISON AND REFERENCE POINTS

The application of different scenarios of XSA with distinct values of natural mortality (M) resulted in the fishing mortalities shown in Figure 43.

The general trends of fishing mortality calculated for every single scenario of natural mortality (Figure 43), present the same shape for each scenario of M, but also some fluctuations which are in decline over years. In the last three years, it observed a slight increase of 0.1/year in the range of the average fishing mortality for all the distinct scenarios despite the low value obtained by using M of Chen Watanabe method.

The scenario of the natural mortality used in GFCM-WG presents the higher harvest value followed by the scenario of Gislason and then the Abella & Caddy scenario.

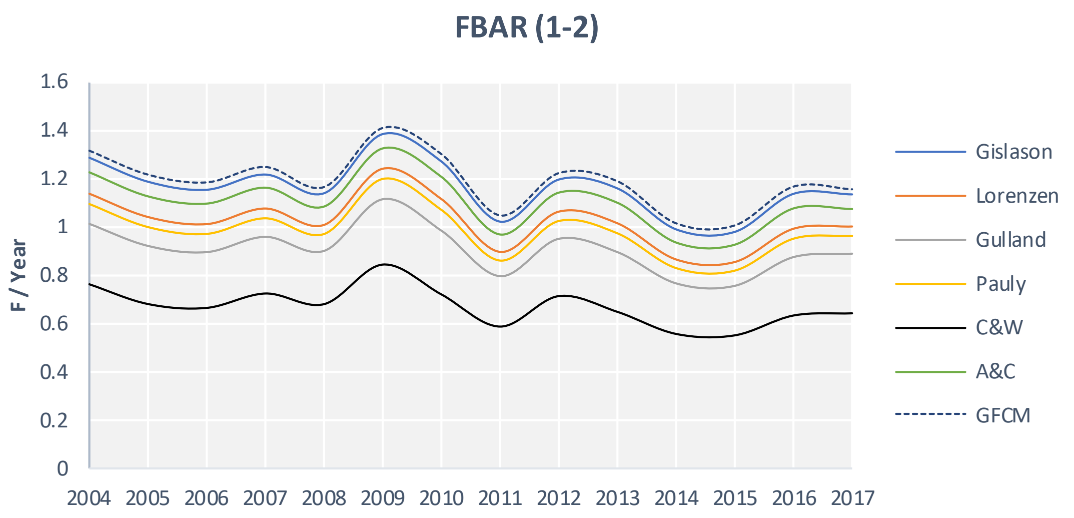


Figure 43: Average fishing mortality estimation over the ages (1-2) from 2004 to 2017 of the red mullet stock in GSA 06 with different scenarios of natural mortality.

The analysis of recruitment seems to be more revealing, a very high estimate of recruitment regarding the assessment using M from Chen & Watanabe method is observed, followed by the scenario of Abella & Caddy (ProdBiom) and then by the GFCM scenario. The methods of estimated M independently from age seems to give the lowest recruitments (Figure 44).

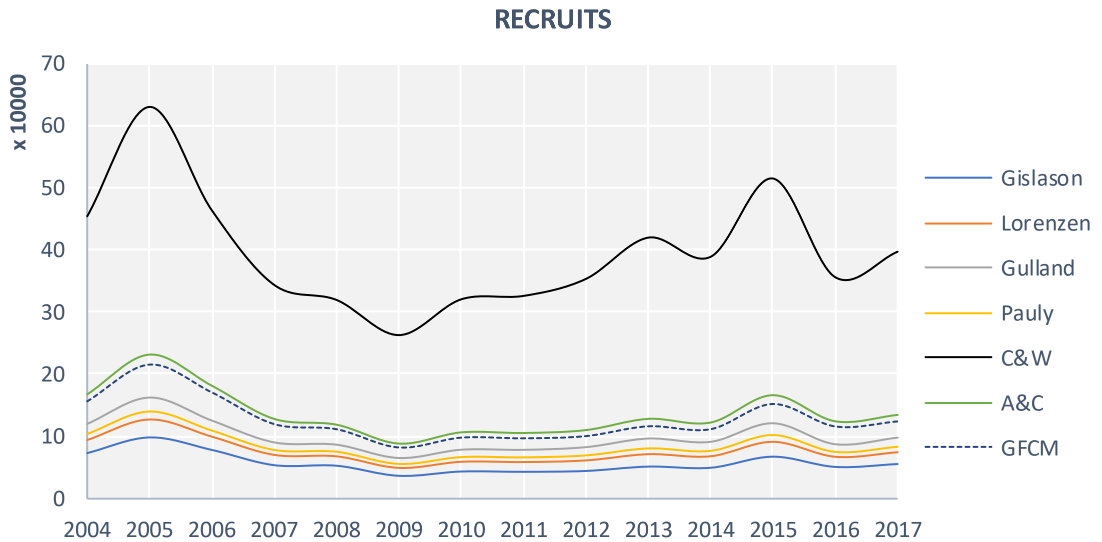


Figure 44: Number of recruits of the red mullet stock estimated with different scenarios of natural mortality

Furthermore, the results of stock spawning Biomass shown in Figure 45 give the same constatations as about recruitment. The use of natural mortality estimated with Chen & Watanabe method, give the noticeable and hight values compared to other methods. The minimum level is for the age-independent methods with scalar M.

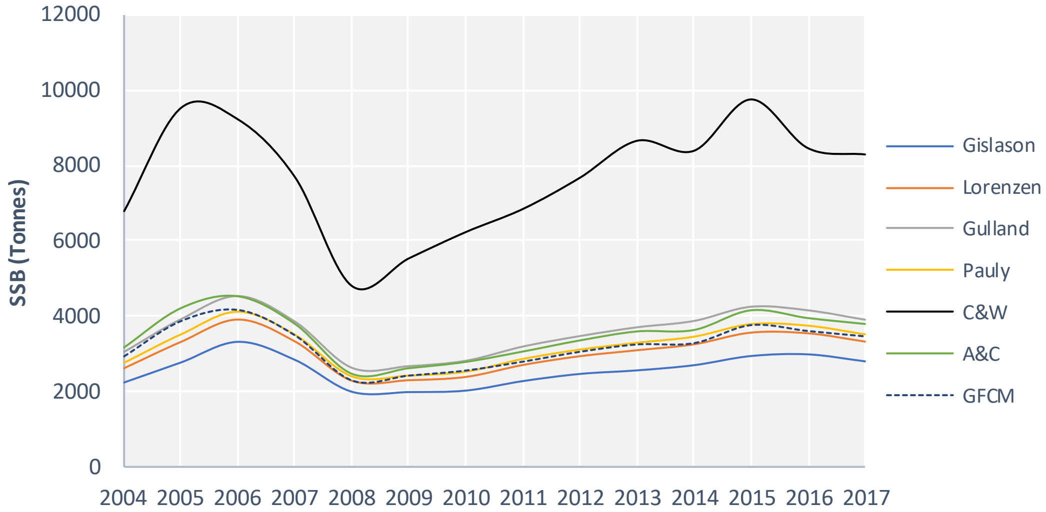


Figure 45: Red mullet' Stock Spawning Biomass trends with different scenarios of natural mortality

REFERENCE POINTS

The results of the seven scenarios of natural mortality (M), is shown in Table 9 where it is so clear from the first observation, that the situation of the red mullet stock presents a **high level of overfishing** status especially for the scenarios: Lorenzen, Pauly, Abella & Caddy and finally for M used in stock assessment (2017).

The assessment using M from Gislason and Gulland provide an **intermediate overfishing** status while the assessment using natural mortality estimated by Chen & Watanabe method presents **low overfishing**.

But the calculation of the exploitation rate for each scenario shows a situation of unsustainability just for Lorenzen scenario and scenarios using the ProdBiom with an extremely high value.

The statistical analysis to choose the best model (Ricker or Beverton & Holt) which fit well the input parameters demonstrates that for all the scenarios except the GFCM one, the model of Beverton fit well notwithstanding that the difference between the two models is very slight.

Moreover, the reference fishing mortality $F_{0.1}$ calculated for each scenario is very small related to the current fishing mortality. This schema is repeated for each scenario and the difference between the two points is important especially for the GFCM scenario.

The yield per recruit function permits to situate each point within a curve (Figure 46) where it's observed a big difference between the two fishing mortality values.

Table 9: Different values of reference point obtained using distinct values of (M)

Parameters \ Method		Gislason	Lorenzen	Gulland	Pauly	Chen & Watanabe	Abella & Caddy	M used in stock assessment (2017)
$F_{0.1}$		0.35	0.46	0.55	0.49	0.58	0.31	0.34
F_{curr}		0.53	0.95	0.84	0.91	0.61	1.02	2.2
F_{msy}		0.63	0.92	5.84	1.04	2.43	0.59	0.44
$F_{curr}/F_{0.1}$		**1.50**	**2.07**	**1.51**	**1.86**	**1.06**	**3.28**	**6.47**
F_{curr}/F_{msy}		0.84	**1.03**	0.14	0.87	0.25	**1.72**	**5**
Overfishing Range of the ratio $F_{curr}/F_{0.1}$	<= 1.33							
	[1.33-1.66]							
	>=1.66							
AIC	Ricker	-30.109	-32.022	-33.475	-32.516	-40.779	-36.4367	**-34.727**
	Beverton & Holt	**-30.112**	**-32.028**	**-33.483**	**-32.522**	**-41.319**	**-36.4369**	-34.704
BIC	Ricker	-28.831	-30.744	-32.197	-31.237	-40.041	-35.1586	**-33.449**
	Beverton & Holt	**-28.834**	**-30.749**	**-32.205**	**-31.244**	**-40.089**	**-35.1588**	-33.426

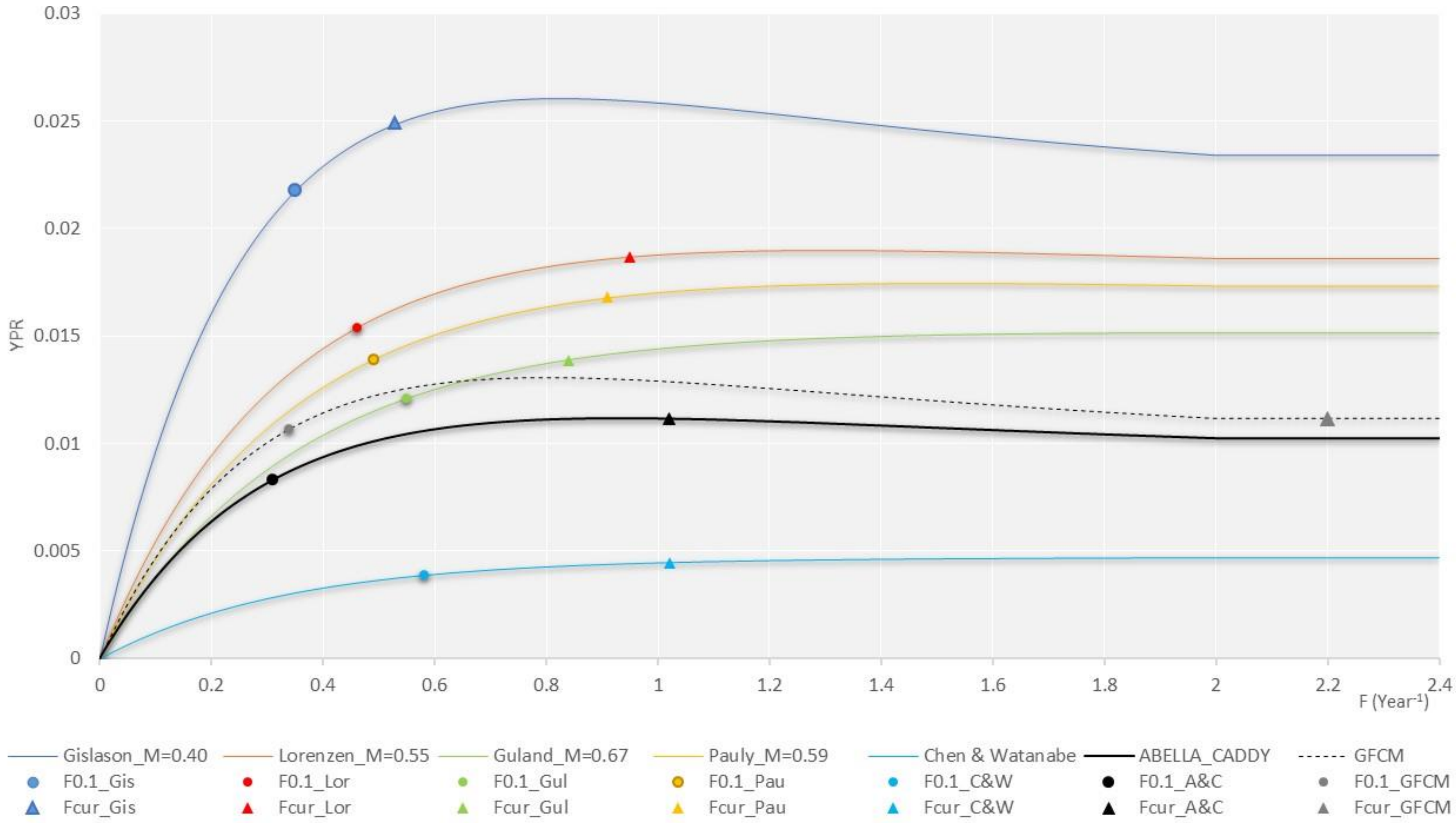


Figure 46: Red mullet' stock Yield per recruit function over a range of fishing mortality based on different (M) scenarios

Diagrammatically, the relationship between the SSB and recruits of the red mullet in GSA 06 appears positive with very pronounced values of the Chen & Watanabe scenarios (Figure 47).

The results of testing the impact of methods used to estimate the natural mortality (M) is shown in (Figure 48) where the residuals appear randomly distributed for scenarios using age-independent mortality and are presenting a curvature which would probably indicate that the relationship between R and SSB is not the reasonable one.

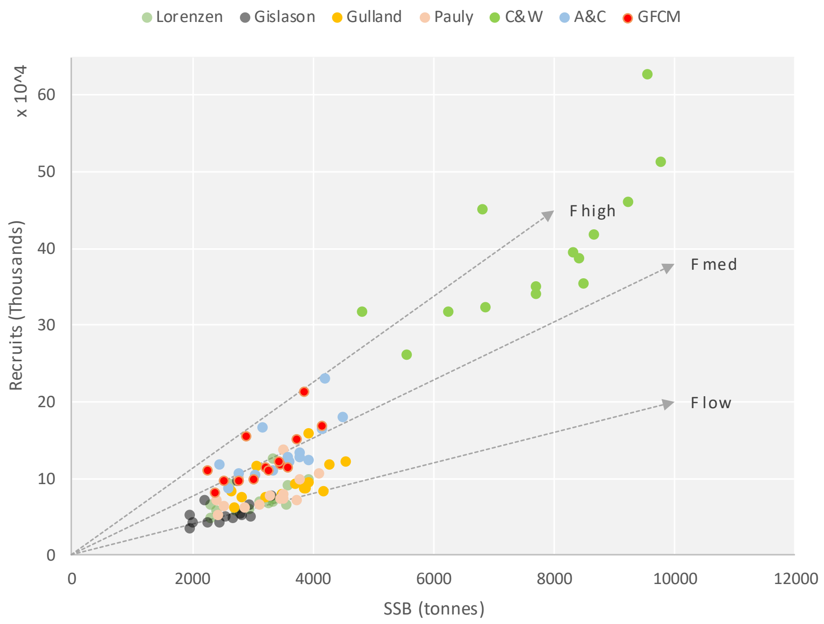
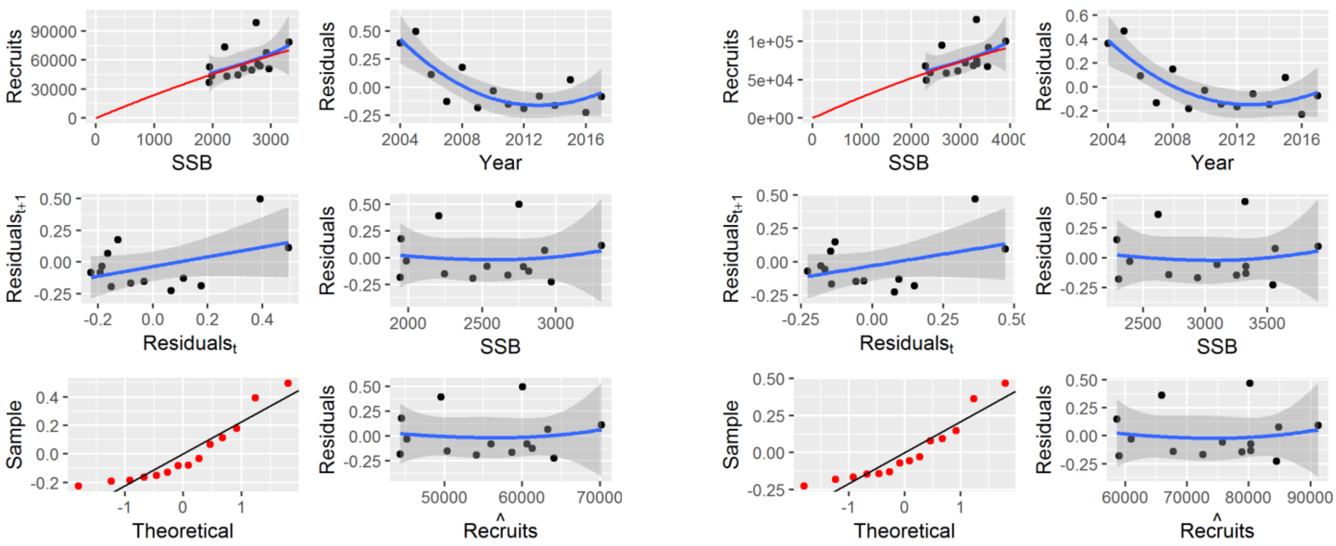
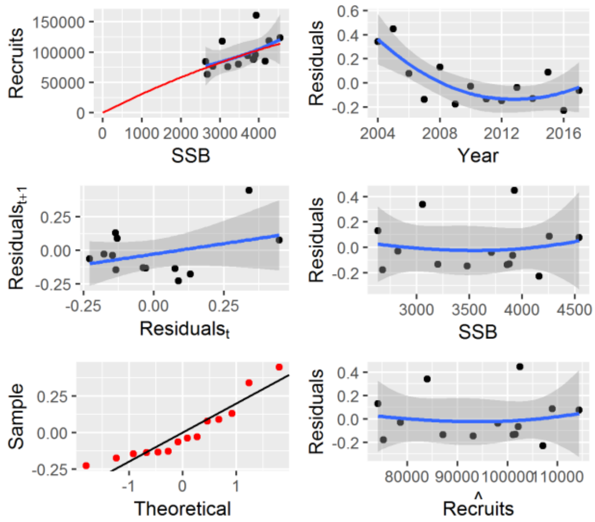


Figure 47: Relationship between the parental stock and recruits of the red mullet' stock in GSA 06

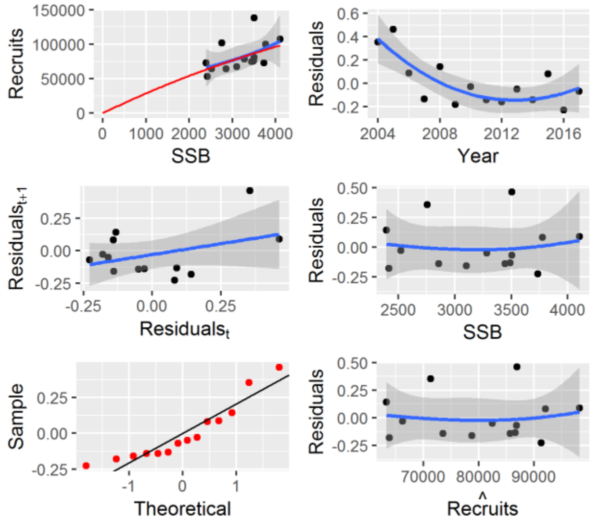
(a)



Gislason (2008) Lorenzen (1996)

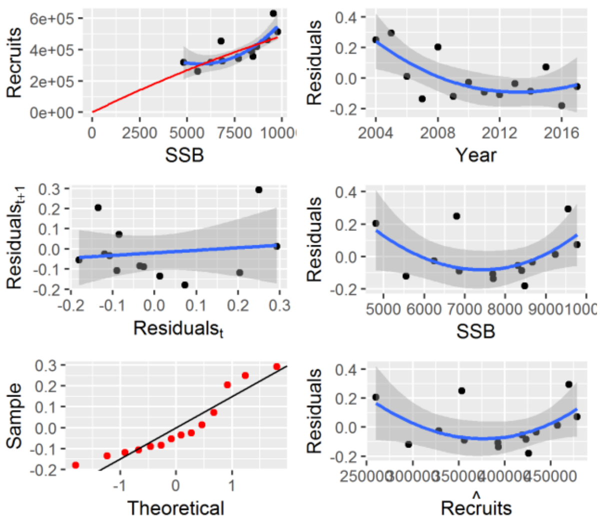


Gulland (1987)

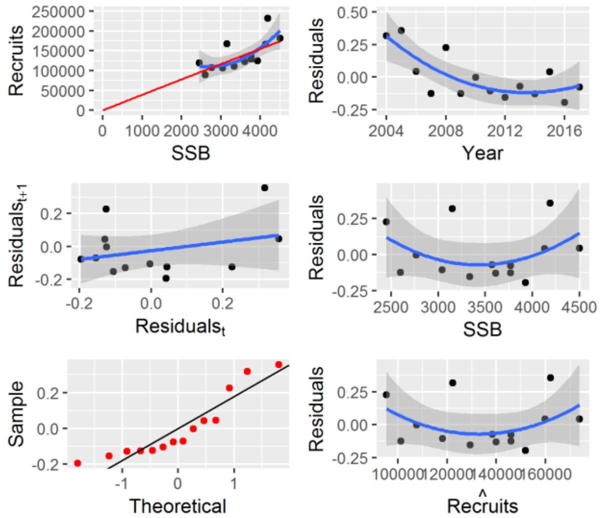


Pauly (1980)

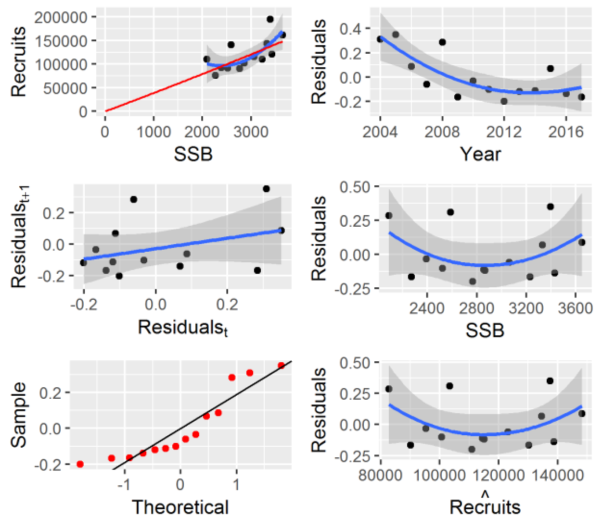
(b)



Chen & Watanabe (1989)



Abella & Caddy (1997)



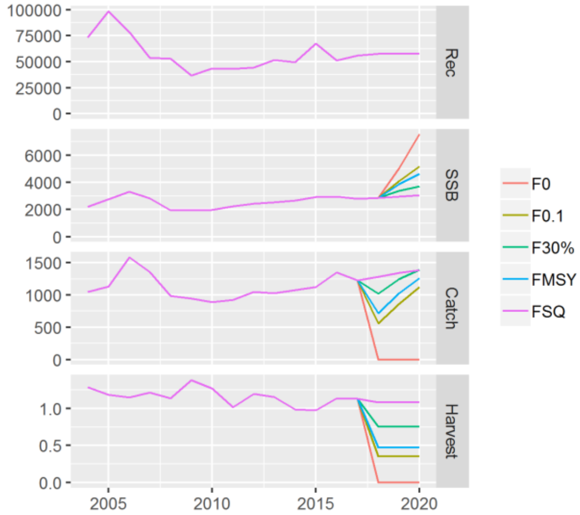
GFCM (Abella & Caddy)

Figure 48: Output of Ricker model simulations scenarios with positive correlation for R-SSB relationship ((a) age-independent methods, (b) age-dependent methods)

III.2.4. SHORT TERM FORECASTING RESULTS

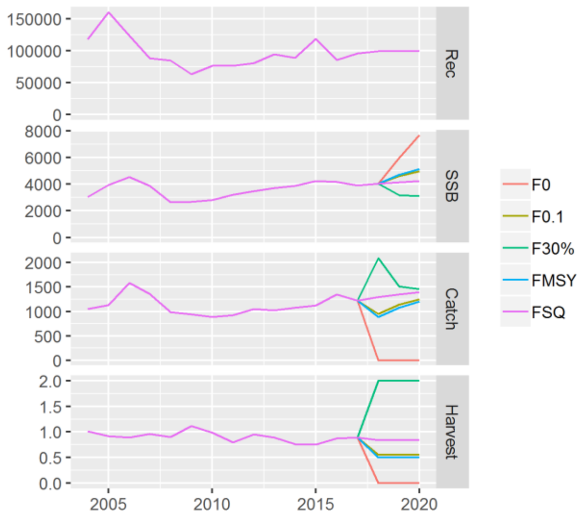
For the forecasting results shown in (Figure 49), it seems that the F_{MSY} and $F_{0.1}$ present the same tendency. Reaching the value of these two reference points contribute to an increase in the catches despite, the first estimations divulge a little decreasing which will rapidly return to increase. The reduction of F by 30% is also an advantage, except for the scenario of Chen & Watanabe where the catch presents an important decline.

(a)

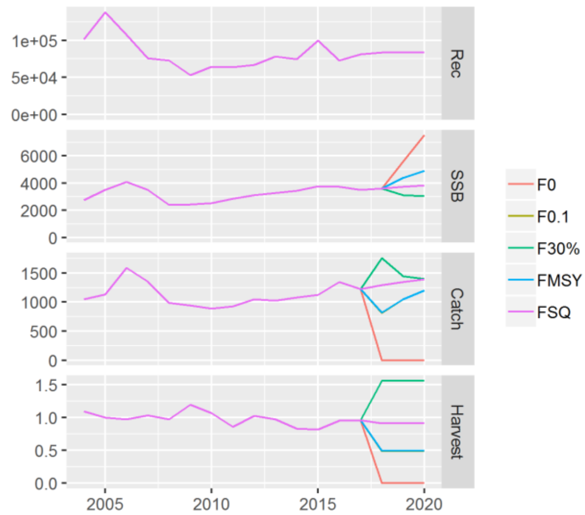


Gislason (2008)

Lorenzen (1996)

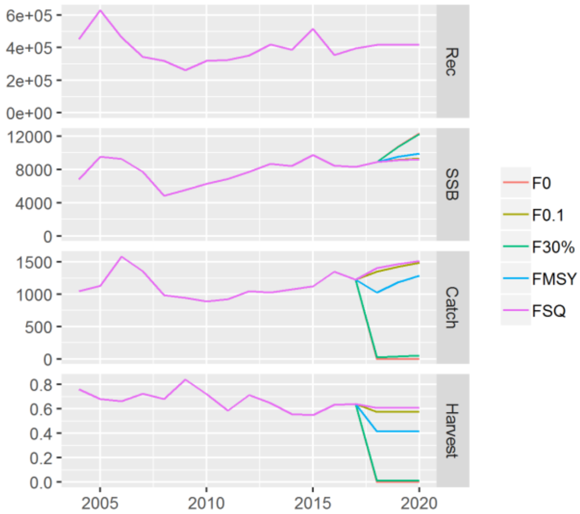


Gulland (1987)



Pauly (1980)

(b)



Chen & Watanabe (1989)

Abella & Caddy (1997)

GFCM (Abella & Caddy)

Figure 49: Outputs of forecasting with different scenarios of natural mortality' estimation

Discussion

Natural mortality (M) is an important parameter which involves in stock assessment models. Sometimes it's notoriously difficult to estimate it, even for well-understood stocks (García-Carreras, et *al*., 2016). The role of this input parameter has been largely ignored and considered as a constant, despite the many kinds of research that are interested in studying it.

Spanish Mediterranean demersal stocks are assessed using several methods agreed by the GFCM. For both the red mullet and red-bleu shrimp, it has been performed a VPA-based method (XSA) with short term projection (Sánchez Lizaso, et *al*., 2018).

The present case of study carries out the XSA and proves the importance of the natural mortality parameter in changing final assessment conclusions, of both demersal stocks, the red-blue shrimp and the red mullet in the GSA 06.

The estimation of natural mortality has been ensured by two categories of methods. The first consists to estimate (M) without considering the age and give an empiric value and the second take into consideration the significant relationship which exists between the age and the natural mortality and assumes that this parameter fluctuates within the age. This has been mentioned by (Gulland, 1987) who demonstrate that when assessing the effect of protection of young fish, it is the value of (M) about the time of recruitment that is important. Using a value that is based on the recruit's population as a whole and which in practice may be based on the older fish, where problems of partial recruitment are less, may, therefore, give misleading results.

The results obtained in this study as regards to the natural mortality estimation are generally similar to the values of (M) used in the GFCMDWG.

Relating to the fishing mortality, it was calculated for the red shrimp between the ages 0 and 3. This choice has been adopted once by the GFCM working groups where it was approved that these age groups are the most representative in landings. From 2017, the average fishing mortality has been set between the ages 1-2 rather than 0-3, based on the high density and abundance of these two groups compared with the age group 0 which is just more present by number. The fishing mortality estimated between these two groups would be higher. The red mullet average fishing mortality is set between 1 and 2 age groups in relation to the representativity of these two groups in landings.

The XSA carried out for both species with different scenarios of assessment with changing the M do not affect the quality of the results from a point of view retrospective analysis. All the scenarios with 5 retro years present a growing SSB started in 2015 which is probably caused by an underestimation of fishing mortality. Gascuel, et *al*. (1995), noticed that an underestimation of fishing mortality results in over-estimation of numbers (including recruitment of cohorts) and biomasses and vice-versa.

Additionally, the comparison of different runs seems to give relatively the same tendency over years whether for the average fishing mortality, the SSB or either the recruits. But, the variation in the value of M and on its nature generate distinct magnitude.

The fluctuations on the recruitments and parental stock of both species are undoubtedly caused by the fluctuations of fishing mortality. High values of (M) involve a low number of recruits and could affect also the SSB and vice-versa.

Rätz, et *al*., (2009), noted that the variation of (M) has a significant effect on the magnitude of stock productivity. In fact, its high rate implies only a minor effect of fishing on the size of the stock and thus on future recruitment.

This pattern was well-marked when natural mortality was estimated with great values as in the case of the empirical methods of Lorenzen and Pauly for the red shrimp and the age-dependent method of Chen & Watanabe for the red mullet.

The variation of (M) is subject to variation of the input parameters as Von Bertalanffy growth parameters as well as the environmental factors. Bellido, et *al*., (2008) list some studies focusing on the effect of environmental changes on fisheries that assume that to a certain extent, fish show the ability to alter their behaviour in response to environmental variations, however, all populations and species have an affinity for environmental conditions most favourable to their survival, growth and reproduction.

With regards to, the input data, Wang, et *al*., (2007), pointed out that, data quality is very important in stock assessment and management and suggest that a careful choice can help reach viable conclusions.

Rätz, et *al*., (2009), concluded that the power of empirical relationships for predicting natural mortality can be rather limited and the uncertainty associated with parameter estimates should be taken into account whenever possible. In the same way, Pascual, et *al*., (1993), declare that the potential error in empirical estimates and its implications for fisheries management should be taken into consideration in the design and execution of stock assessment programs.

Concerning this matter, it has been justified by the present work that the use of empirical (M) could conduct to several different estimations which depends on the magnitude of the parameter. In another context, the results of the application of the age-dependent methods seem to give a suitable assessment' models.

In his paper, Abella et *al*., (1998) proved that for the Meditteranean demersal fisheries, it becomes positively dangerous to assume that a constant natural mortality rate applies during the first few years of life and it is justifiable and precautionary to explore the results of the assumption that natural mortality in the Mediterranean demersal stocks follows a reciprocal relationship with age and consider to implicate it.

With respect to the fisheries biological reference points, testing multiple scenarios with distinct values of M, have divulgated the sensitivity of assessments models to the input parameters as well as the natural mortality.

Sánchez Lizaso, et *al*., (2018), noted that the GFCM based its advice on fishing mortality reference points (F_{MSY} or $F_{0.1}$) when analytical assessments allowed for an accurate estimation. In the present study, the calculation of the ratio $F_{curr}/F_{0.1}$, express **an Overfishing status for both species** whatever the value of natural mortality. This concord with the results presented respectively by (Esteban, et *al*., 2017) and (García Rodríguez, et *al*., 2017) on red bleu shrimp and red mullet of the GSA 06, in GFCM working group on the demersal fisheries.

The GFCM has recommended the reduction of the current fishing mortality towards the fishing mortality set as a reference point ($F_{0.1}$) and highlight the use of a vectorial method for the estimation of natural mortality and add that it's important to take into account the input parameters for the assessment because the latter vary with little changes.

This ascertainment has been cited by (García-Carreras, et *al*., 2016), where they mentioned that the shape of yield per recruit curve and hence the value of reference points, especially Fmax, are particularly sensitive to small changes in input parameters such as k and (M), because these may lead to flat-topped curves with maxima that are difficult to define.

on the other hand, the exploitation rate, the scenarios tested within this study present some convergent conclusions about the sustainability of the two stocks using different values of natural mortality (M). Vasilakopoulos, et *al*., (2014) evocate this point and noted that the rate of F_{curr}/F_{MSY} indicates unsustainability exploitation of the stocks. This situation is clearly visible when using vectorial values of M as it is the case of the Prodbiom method.

The same authors remark that the red mullet Mediterranean stocks lay within the lowest (SSB) area due to the combination of high (F) and the fishery selectivity at the population level which means the difference in years between the age at which 50% of fish are selected if they encounter the fishing gears and the age which 50% of the fish are mature. This result has conducted the authors to suggest that it is not sufficient to reduce the exploitation rates but mainly to improve selectivity.

In the same way, conducting a model which can test the relationship between the recruits (R) and the spawning stock biomass (SSB) is a step to verify the impact of changing natural mortality (M) over the stock assessment process. Patterson, et *al*., (2001), highpoint the importance of this latter and noted that it is necessary to model the relationship between stock and recruitment to conduct forecasts. Sparholt, (1996), suggest that a causal relationship between stock and recruitment has important implication for the management of the fishery.

In the present case of study, it has been clearly concluded that the use of vectorial natural mortality has a large impact on the quality of stock-recruitment' models. This constatation reinforces the results discussed before and so the theory of using a reciprocal relationship with age to estimate natural mortality rates.

This has been demonstrated by (Jakobsen, 1993) that for fish stock assessments if (M) is changed in VPA, both fishing mortality and stock size will change. If (M) is increased, F will decrease and stock numbers will increase. Furthermore, F at all age groups will decrease by roughly the same amount M is increased by. The author explains that the total mortality rate Z in a VPA tends to remain fairly constant over a reasonably chosen range of (M) values.

The short-term forecasting results evocated for the two undertaken species, consider the reduction of the current harvest towards the $F_{0.1}$, F_{MSY} or either F30%. This recommendation enhances the SSB for the majority of assessments and probably will help to recover the stocks in the future.

CONCLUSION

CONCLUSION

At the end of this work, it is approved that the Mediterranean fisheries are nowadays in a critical state regarding the situation of exploitation of the majority of stocks. Analytically managed by the GFCM and STECF (for the European side), where management' advice could be pronounced, the situation of unsustainability persists especially for the target species defined as most important at the Mediterranean Sea. In addition, it has been agreed in several working groups whether it is in Mediterranean level, European level or even in the local level, that the importance of the input parameters in the stock assessment process could conduct to distinct conclusions and so, management plans. As the risk and susceptibility analyse become more frequent, decisions on performing the manner that provides input parameters for decision-makers is often taken into account to ensure better and sustainable ways of resources' exploitation.

For the present case of study, the importance of natural mortality which consists of one of the fundamental parameters that involve the stock assessment strategy is highlighted. And so, it has been demonstrated its main role in the decision-making process through its contribution to the establishment of the reference points.

In the same way, many works and studies have been undertaken to evaluate the truthiness of the natural mortality parameter and to establish methods that can help scientists to determine the natural losses in an exploitable stock with fewer errors and in the same time try to describe the stocks' behaviour towards the fishing intensity. For that, the conclusion that could be pronounced regarding the present study could be noted as follow:

Firstly, the natural mortality is now days considered as a key parameter and it's very important to focus on this criterion in order to ensure a better understanding of exploitable stock' behaviour as it is the case in the present study on the red and blue shrimp and the red mullet. Thus, to minimize the risk of underestimating the different variations that may occur but also to take into account the various events that could be experienced during the stock's life cycle.

In other side, the sensitivity of the life cycle to the variation in fishing mortality demonstrated by (Jørgensen and Holt., 2013) reinforces the theory of the non-stability of natural mortality during the whole life of the exploitable species. According to the same authors, the intensity of fishing plays an important role in the evolution of stock life by accelerating growth and promoting early maturation. Moreover, the high overfishing of the red shrimp and the red mullet need to improve research assessment and taking into account every single parameter that participates in the assessment process. It's so important to adopt an age-dependent method for the estimation of natural mortality so it considers the fluctuations of this parameter regarding the length of the species and avoids it misestimation depending on the age (recruits and very old individuals presents a very high natural mortality rate than the other categories).

In conclusion, the establishment of the reference points presents a high sensibility to the natural mortality so the fluctuation of this parameter contributes to change the conclusion that could be pronounced regarding these points. For many organisms, these reference points are considered the best tools that can be presented to decision-makers and so the best way to establish management plans.

RECOMMENDATIONS AND FUTURE STEPS

The different recommendations that can be drawn from this work are as follow:

- Adopt the ProdBiom method for the estimation of the natural mortality and generalize it for all the Mediterranean countries so it will be easier for the assessment working groups to estimate the situation of the important stocks in the Mediterranean area;

- Take into account the areas where the stocks present a data-poor situation and try to enhance researches in this field;

- Similar studies could be undertaken for other species with other methods, for example, the a4a or Stock synthesis (SS3) that introduce uncertainties when estimating the natural mortality (M) and also by considering the environmental changes as an additional factor.

- It's very significant to highlight the emergency of enhancing investigations that could present a clear image of the exploitation rates.

- The establishment of reference points has to base on parameters that take into account the selectivity parameter and its interactions with other parameters like the mortalities. The combination of selectivity and fishing mortality reduction will be an improvement for the Mediterranean fisheries;

- Underpin and standardize the data collection protocol for all the Mediterranean fisheries to guarantee good stock assessments for the whole area.

- It's true that the red mullet is captured by the trawlers, but it also harvested by small scale fisheries and so it's important to consider this point when proceeding to its assessment.

- Consider the importance of stock boundaries to involve other scientific organisms like the STECF to better understand the Mediterranean problems especially for the south side.

BIBLIOGRAPHY

BIBLIOGRAPHY

Abella A.J., Caddy J.F., Serena F. 1998. Estimation of the parameters of the Caddy reciprocal M-at-age model for the construction of natural mortality vectors. 1998. Cahiers Options Méd., 35: 191-200.

Bellido, J. M., Brown, A. M., Valavanis, V. D., Giráldez, A., Pierce, G. J., Iglesias, M., & Palialexis, A. 2008. Identifying essential fish habitat for small pelagic species in Spanish Mediterranean waters. 2008. In Essential Fish Habitat Mapping in the Mediterranean (pp. 171-184). Springer, Dordrecht.

Beyer, J. E., Kirchner, C. H., and Holtzhausen, J. A. 1999. A method to determine size-specific natural mortality applied to westcoast steenbras (Lithognathus aureti) in Namibia. 1999. Fisheries Research, 41(2), 133-153.

Caddy, J. F. 1991. Death rates and time intervals: is there an alternative to the constant natural mortality axiom? 1991. Reviews in Fish Biology and Fisheries,1(2), 109-138.

Di Natale, A., Rätz, H.J., & Cheilari, A. 2009. Scientific, Technical and Economic Committee for Fisheries (STECF) - Report of the Workshop on Mediterranean Stock Assessment Standardization SG-ECA/RST/MED 09-01. 2009. 2-6 March 2009, Murcia, Spain, 58pp.

Esteban, A., Pérez Gil, J.L., García-Rodríguez, E., Vivas, M. & Herrera, E. 2017. Stock assessment form of the blue and red shrimp (Aristeus antennatus) of the trawl fisheries of the GSA 6, Northern Spain (2004-2017). *GFCM/SCSA Working Group on Stock Assessment of Demersal Species (WGSAD).* Rome, Italy : 13-18 November, 2017. 34 p.

Fabozzi, F. J., Focardi, S. M., Rachev, S. T., & Arshanapalli, B. G. 2014. The basics of financial econometrics: Tools, concepts, and asset management applications. 2014. John Wiley & Sons, 399-403.

FAO. 2018-a. The State of World Fisheries and Aquaculture. 2018-a. Meeting the sustainable development goals. Rome.Licence: CC BY-NC-SA 3.0 IGO, 277 p.

FAO. 2018-b. The State of Mediterranean and Black Sea Fisheries. 2018-b. General Fisheries Commission for the Mediterranean. Rome. 172 p.

Fogarty, M. J., and Collie, J. S. 2009. Fisheries Overview. 2009. Encyclopedia of Ocean Sciences (Second Edition), Academic Press, pp 499-504.

García Rodríguez, E., Vivas, M., Herrera, E., Esteban, A. & Pérez-Gil, J.L. 2017. Stock assessment form of the red mullet (Mullus barbatus) of the trawl fisheries of the GSA 6, Northern Spain (2004-2017). *GFCM/SCSA Working Group on Stock Assessment of Demersal Species (WGSAD).* Rome, Italy : 13-18 November, 2017. 29p.

Garcıa, D., Prellezo, R., Sánchez, S., Andrés, M., Urtizberea, A., & Carmona, I. 2019. Technical manual for FLBEIA a R package to conduct Bio-Economic Impact assessments using FLR. 2019. (version 1.15).

García-Carreras, B., Jennings, S., & Le Quesne, W. J. 2016 . Predicting reference points and associated uncertainty from life histories for risk and status assessment. 2016 . ICES Journal of Marine Science, 73(2), 483-493..

Gascuel, D., Fonteneau, A., & Durand, J. L. 1995. Les Recherches françaises en évaluation quantitative et modélisation des ressources et des systèmes halieutiques. 1995. ORSTOM éditions. 105-123..

Gislason, H., Daan, N., Rice, J. C., & Pope, J. G. 2010. Size, growth, temperature and the natural mortality of marine fish. 2010. Fish and Fisheries, 11(2), 149-158.

Gulland, J. A. (1987). 1987. Natural mortality and size. 1987. Marine ecology progress series. Oldendorf, 39(2), 197-199.

Hamon, K., Kell, L., & Garcia, D. 2017. Reference points for fisheries management with FLBRP. 2017. flr-project.org.

ICES. 2008. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak—Spring and Autumn (WGNSSK). 2008. 1–8 May 2007: 903-912.

Jakobsen, T. 1993. The behaviour of Flow, Fmed and Fhigh in response to variation in parameters used for their estimation. 1993. SJ Smith, J. Hunt and D. Rivard (ed's), Risk Evaluation and biological reference points for fisheries management. National Research Council of Canada, Canadian Special Publication of Fisheries and Aquatic Sciences, 120, 119-125..

Jørgensen, C., & Holt, R. E. 2013. Natural mortality: its ecology, how it shapes fish life histories, and why it may be increased by fishing. 2013. Journal of Sea Research, 75, 8-18..

Kafaf, O. 2017. Trends on the state of Mediterranean fish Stocks. 2017. Master thesis, University of Alicante, 167p.

Kilduff, P., Carmichael, J., & Latour, R. 2009. Guide to fisheries science and stock assessments. 2009. Atlantic States Marine Fisheries Commission, National Oceanic and Atmospheric Administration Grant No. NA05NMF4741025, 74 p.

Lassen, H., & Medley, P. 2001. Virtual population analysis: a practical manual for stock assessment. 2001. FAO Fisheries Technical Paper. No. 400. Rome, 129pp.

Lee, H. H., Maunder, M. N., Piner, K. R., and Methot, R. D. 2011. Estimating natural mortality within a fisheries stock assessment model: an evaluation using simulation analysis based on twelve stock assessments. 2011. Fisheries Research, 109(1), 89-94.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. 1996. Journal of fish biology, 49(4), 627-642.

Mannino, A. M., Balistreri, P., and Deidun, A. 2017. The marine biodiversity of the Mediterranean Sea in a changing climate: the impact of biological invasions. 2017. In Mediterranean Identities-Environment, Society, Culture. IntechOpen.

Papaconstantinou, C., Farrugio, H. 2000. Fisheries in the Mediterranean. 2000. Mediterranean Marine Science, 1(1), 5-18. doi:http://dx.doi.org/10.12681/mms.2.

Pascual, M. A., & Iribarne, O. O. 1993. How good are empirical predictions of natural mortality? 1993. Fisheries Research, 16(1), 17–24. .

Patterson, K., Cook, R., Darby, C., Gavaris, S., Kell, L., Lewy, P., Mesnil, B., Punt, A., Restrepo, V., Skagen D-W., & Stefánsson, G. 2001. Estimating uncertainty in fish stock assessment and forecasting. 2001. Fish and fisheries, 2(2), 125-157..

Poos, J-J., Hamon, K. 2017. Short Term Forecasting for advice using FLash. 2017. flr-project.org.

Querol, N.S. 2017. Aplicación de un modelo de evaluación de pesquerías mixtas a la de arrastre de plataforma en el área GSA 6 del mediterráneo. 2017. Master thesis, University of Alicante, P 8.

Ragonese, S., Biondo, F., & Vitale, S. 2018. A standard procedure for estimating natural mortality (M) at age for the Mediterranean groundfish resources. 2018. NTR-ITPP, sr82: 26 p.

Raicevich, S., Alegret, J. L., Frangoudes, K., Giovanardi, O., and Fortibuoni, T. 2018. Community-based management of the Mediterranean coastal fisheries: Historical reminiscence or the root for new fisheries governance? 2018. Regional Studies in Marine Science, 21, 86-93.

Rätz, H-J., Cheilari, A., & Lloret, J. 2009. The effect of M on the estimation of stock state parameters and derived references for sustainable fisheries management. 2009. STECF SG/ECA/RST/MED 09-01 Working paper, 14 p.

Sánchez Lizaso, J. L., Sola, I., Guijarro-García, E., González-Carrión, F., Franquesa, R. and Bellido, J.M. 2018. Research for PECH Committee Discard ban, Landing Obligation and MSY in the Western Mediterranean Sea - the Spanish Case. 2018. European Parliament, Policy Department for Structural and Cohesion Policies, Brussels 59p.

Santinelli, C. 2015. DOC in the Mediterranean Sea In Biogeochemistry of marine dissolved organic matter. 2015. Academic Press pp 579-608.

Schroeder, K., Garcìa-Lafuente, J., Josey, S. A., Artale, V., Nardelli, B. B., Carrillo, A., ... and Ludwig, W. 2012. Circulation of the Mediterranean Sea and its variability. The climate of the Mediterranean region. 2012. pp. edited by: Lionello, P., Elsevier, 187-256. pp.edited by: Lionello, P., Elsevier, 187-256.

Secretaría General de Pesca. 2017. Sale sheets and landings of the blue and red shrimp and the red mullet in the GSA 6. 2017.

Shepherd, J. G. 1999. Extended survivors' analysis: An improved method for the analysis of catch-at-age data and abundance indices. 1999. ICES Journal of Marine Science, 56(5), 584-591.

Simpfendorfer, C. A., Bonfil, R., & Latour, R. J. 2012. Mortality estimation. 2012. FAO Fisheries Technical Paper, Chapter 8, 474-127.

Smith, S. J., Hunt, J. J., and Rivard, D. . 1993. Risk evaluation and biological reference points for fisheries management. 1993. Can. Spec. Publ. Fish. Aquat. Sci. 120: viii + 442p. .

Sparholt, H. 1996. Causal correlation between recruitment and spawning stock size of central Baltic cod? 1996. ICES Journal of marine science, 53(5), 771-779.

Vasilakopoulos, P., Maravelias, C. D., & Tserpes, G. 2014. The alarming decline of Mediterranean fish stocks. 2014. Current Biology, 24(14), 1643-1648..

Wang, Y., Liu, Q., & Wang, Y. 2007. Estimation of natural mortality coefficient from fish abundance and catch data using Virtual Population Analysis (VPA). 2007. Journal of Ocean University of China, 6(1), 53-59..

Wilberg, M. J., Thorson, J. T., Linton, B. C., & Berkson, J. 2009. Incorporating time-varying catchability into population dynamic stock assessment models. 2009. Wilberg, M. J., Thorson, J. T., Linton, B. C., & Berkson, J. (2009). IncorpReviews in Fisheries Science, 18(1), 7-24.).

ANNEX

ANNEX

Scripts

```
##################Scripts used for the different assessments##################
rm(list=ls())
setwd("D:/IEO/XSA/ARA/LGFCM")
library(gridExtra)
library(copula)
library(triangle)
library(mgcv)
library(splines)
library(plyr)
library(ggplot2)
library(knitr)
library(FLCore)
library(FLEDA)
library(FLXSA)
library(FLAssess)
library(FLash)
require(plyr)
require(FLBRP)
library(ggplotFL)
##read stock file
aa.stk <- readFLStock("comercial/LOWIND.DAT", no.discards=TRUE) #only commercial data
aa.stk
#set up the stock (create the empty matrix)
units(harvest(aa.stk))<-"f"
range(aa.stk)["minfbar"] <- 0
range(aa.stk)["maxfbar"] <- 3
aa.stk
# Set the plus group
aa.stk <- setPlusGroup(aa.stk, 4)
#read index (tuning file)
```

```
aa.idx <- readFLIndices("medits/TUNEFF.DAT")
name(aa.idx[[1]]) <- "MEDITS"
aa.idx[[1]]<-trim(aa.idx[[1]], age=0:3)
(catch(aa.stk)-landings(aa.stk))/landings(aa.stk)*100
###Set the control object###
q=1
shk.age=3
rage=1
#representation of the catch per age
bubbles(age~year, data=(catch.n(aa.stk)), bub.scale=5)
bubbles(age~year, data=(catch.wt(aa.stk))[0:5,], xlab='year', bub.scale=10, col="#333333")
bubbles(age~year, data=catch.n(aa.stk)[0:5,], xlab='year', bub.scale=10, col="#333333")
mat(aa.stk)
m(aa.stk)
plot(rnorm(200, m(aa.stk), 0.20), probs=c(0.05, 0.10, 0.25, 0.50, 0.75, 0.90, 0.95))
harvest.spwn(aa.stk)
landings.n(aa.stk)
landings(aa.stk)
stock.n(aa.stk)
stock.wt(aa.stk)
#####SOP correction#####
landingssop<-apply(landings.wt(aa.stk) * landings.n(aa.stk),2,sum)
x<-landings(aa.stk)/landingssop
landings.n.sop<-landings.n(aa.stk)%*%x
#newcheck
apply(landings.wt(aa.stk) * landings.n.sop,2,sum)
landings(aa.stk)
#change to new values in FLStock object
landings.n(aa.stk)<-landings.n.sop
```

```
catch.n(aa.stk)<-landings.n.sop
catch<-landings
plot(aa.stk)
ggsave("catch.png",plot(aa.stk))
# To plot numbers at age by year
xyplot(data~age, group= year, data=catch.n(aa.stk), main="Catches age structure",
    type=c("g", "l"), ylab= "N (thousands)", auto.key=list(title="Year",points=F,
                                    lines=T, space="right"))
xyplot(data/1000~year, groups=age, data=catch.n(aa.stk), type= c("g", "l"),
    auto.key=list(space='bottom',columns=5, cex=0.7),
    ylab='Catch numbers at age (10^6)',xlab='')
xyplot(data/1000~year|factor(age), data=catch.n(aa.stk), type='l',
    scales = list(y = list(relation = 'free')), ylab='Catch numbers (10^6)',xlab='')
xyplot(data~year|factor(age), data=landings.wt(aa.stk), type='l',
    scales = list(y = list(relation = 'free')), ylab='landings.wt',xlab='')
################# sensitivity analysis changing rage and qage##################
FLXSA.control.aa <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1,
                      rage=0, qage=1, shk.n=TRUE, shk.f=TRUE, shk.yrs=3, shk.ages=3,
                      window=100, tsrange=20, tspower=3, vpa=FALSE)
FLXSA.control.aa1 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1,
                      rage=0, qage=2, shk.n=TRUE, shk.f=TRUE, shk.yrs=3, shk.ages=3,
                      window=100, tsrange=20, tspower=3, vpa=FALSE)
FLXSA.control.aa2 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1,
                      rage=1, qage=2, shk.n=TRUE, shk.f=TRUE, shk.yrs=5, shk.ages=3,
                      window=100, tsrange=20, tspower=3, vpa=FALSE)
FLXSA.control.aa3 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1,
                      rage=1, qage=3, shk.n=TRUE, shk.f=TRUE, shk.yrs=3, shk.ages=3,
                      window=100, tsrange=20, tspower=3, vpa=FALSE)
FLXSA.control.aa4 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1,
```

```
                        rage=1, qage=4, shk.n=TRUE, shk.f=TRUE, shk.yrs=3, shk.ages=3,
                        window=100, tsrange=20, tspower=3, vpa=FALSE)
FLXSA.control.aa5 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1,
                        rage=0, qage=3, shk.n=TRUE, shk.f=TRUE, shk.yrs=3, shk.ages=3,
                        window=100, tsrange=20, tspower=3, vpa=FALSE)
FLXSA.control.aa6 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1,
                        rage=0, qage=4, shk.n=TRUE, shk.f=TRUE, shk.yrs=3, shk.ages=3,
                        window=100, tsrange=20, tspower=3, vpa=FALSE)
FLXSA.control.aa7 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1,
                        rage=-1, qage=3, shk.n=TRUE, shk.f=TRUE, shk.yrs=3, shk.ages=3,
                        window=100, tsrange=20, tspower=3, vpa=FALSE)
FLXSA.control.aa8 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1,
                        rage=-1, qage=2, shk.n=TRUE, shk.f=TRUE, shk.yrs=3, shk.ages=3,
                        window=100, tsrange=20, tspower=3, vpa=FALSE)
#####Running the assessments with different settings
aa.xsa <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa)
aa.xsa1 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa1)
aa.xsa2 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa2)
aa.xsa3 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa3)
aa.xsa4 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa4)
aa.xsa5 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa5)
aa.xsa6 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa6)
aa.xsa7 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa7)
aa.xsa8 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa8)
#####Add the results to the stock files
aa.stk <- aa.stk+aa.xsa
aa.stk1 <- aa.stk+aa.xsa1
aa.stk2 <- aa.stk+aa.xsa2
aa.stk3 <- aa.stk+aa.xsa3
```

```
aa.stk4 <- aa.stk+aa.xsa4
aa.stk5 <- aa.stk+aa.xsa5
aa.stk6 <- aa.stk+aa.xsa6
aa.stk7 <- aa.stk+aa.xsa7
aa.stk8 <- aa.stk+aa.xsa8
stocks <- FLStocks(aa.stk,aa.stk1,aa.stk2,aa.stk3,aa.stk4,aa.stk5,aa.stk6,aa.stk7,aa.stk8)
names(stocks)<- c("r0q1","r0q2","r1q2","r1q3","r1q4","r0q3","r0q4","r-1q3","r-1q2")
plot(stocks)
ggsave("stocks.png",plot(stocks))
###Residuals by fleet
bubbles(age ~ year|qname, data = index.res(aa.xsa), main = "Proportion at age by year r0q1")
bubbles(age ~ year|qname, data = index.res(aa.xsa1) , main = "Proportion at age by year r0q2")
bubbles(age ~ year|qname, data = index.res(aa.xsa2) , main = "Proportion at age by year r1q2")
bubbles(age ~ year|qname, data = index.res(aa.xsa3), main = "Proportion at age by year r1q3")
bubbles(age ~ year|qname, data = index.res(aa.xsa4), main = "Proportion at age by year r1q4")
bubbles(age ~ year|qname, data = index.res(aa.xsa5), main = "Proportion at age by year r0q3")
bubbles(age ~ year|qname, data = index.res(aa.xsa6), main = "Proportion at age by year r0q4")
bubbles(age ~ year|qname, data = index.res(aa.xsa7), main = "Proportion at age by year r-1q3")
bubbles(age ~ year|qname, data = index.res(aa.xsa8), main = "Proportion at age by year r-1q2")
####### sensitivity analisys on shrinkage age#########
FLXSA.control.stk <- FLXSA.control(x=NULL, tol=1e-09, maxit=150, min.nse=0.3, fse=1.0,
                        rage=0, qage=1, shk.n=TRUE, shk.f=TRUE, shk.yrs=2, shk.ages=1,
                        window=100, tsrange=20, tspower=3, vpa=FALSE)
FLXSA.control.stk1 <- FLXSA.control(x=NULL, tol=1e-09, maxit=150, min.nse=0.3, fse=1.0,
                        rage=0, qage=1, shk.n=TRUE, shk.f=TRUE, shk.yrs=2, shk.ages=2,
                        window=100, tsrange=20, tspower=3, vpa=FALSE)
FLXSA.control.stk2 <- FLXSA.control(x=NULL, tol=1e-09, maxit=150, min.nse=0.3, fse=1.0,
                        rage=0, qage=1, shk.n=TRUE, shk.f=TRUE, shk.yrs=2, shk.ages=3,
                        window=100, tsrange=20, tspower=3, vpa=FALSE)
```

```
#Running the assessments with different settings

aa.xsa <- FLXSA(aa.stk, aa.idx, FLXSA.control.stk)

aa.xsa1 <- FLXSA(aa.stk, aa.idx, FLXSA.control.stk1)

aa.xsa2 <- FLXSA(aa.stk, aa.idx, FLXSA.control.stk2)

#Add the results to the stock files

aa.stk <- aa.stk+aa.xsa

aa.stk1 <- aa.stk+aa.xsa1

aa.stk2 <- aa.stk+aa.xsa2

stocks1 <- FLStocks(aa.stk,aa.stk1,aa.stk2)

names(stocks1)<- c("shk.ages=1","shk.ages=2","shk.ages=3")

plot(stocks1)

ggsave("ShAge.png",plot(stocks1))

###Residuals by fleet

bubbles(age ~ year|qname, data = index.res(aa.xsa), main = "Proportion at age by year shk.ages=1")

bubbles(age ~ year|qname, data = index.res(aa.xsa1), main = "Proportion at age by year shk.ages=2")

bubbles(age ~ year|qname, data = index.res(aa.xsa2), main = "Proportion at age by year shk.ages=3")

#####################Shrinkage ###################

### shrinkage 0.5

FLXSA.control.aa <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=0.5,

                        rage=0, qage=1, shk.n=TRUE, shk.f=TRUE, shk.yrs=2, shk.ages=2,

                        window=100, tsrange=20, tspower=3, vpa=FALSE)

### shrinkage 1.0 (fse=1)

FLXSA.control.aa1 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1.0,

                        rage=0, qage=1, shk.n=TRUE, shk.f=TRUE, shk.yrs=2, shk.ages=2,

                        window=100, tsrange=20, tspower=3, vpa=FALSE)

### shrinkage 2.0

FLXSA.control.aa2 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=2.0,
```

```
                              rage=0, qage=1, shk.n=TRUE, shk.f=TRUE, shk.yrs=2, shk.ages=2,
                              window=100, tsrange=20, tspower=3, vpa=FALSE)
### shrinkage 1.5
FLXSA.control.aa3 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=1.5,
                              rage=0, qage=1, shk.n=TRUE, shk.f=TRUE, shk.yrs=2, shk.ages=2,
                              window=100, tsrange=20, tspower=3, vpa=FALSE)
### shrinkage 3.0
FLXSA.control.aa4 <- FLXSA.control(x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=3.0,
                              rage=0, qage=1, shk.n=TRUE, shk.f=TRUE, shk.yrs=2, shk.ages=2,
                              window=100, tsrange=20, tspower=3, vpa=FALSE)
### shrinkage 2.5
FLXSA.control.aa5 <- FLXSA.control( x=NULL, tol=1e-09, maxit=30, min.nse=0.3, fse=2.5,
                               rage=0, qage=1, shk.n=TRUE, shk.f=TRUE, shk.yrs=2, shk.ages=2,
                               window=100, tsrange=20, tspower=3, vpa=FALSE)
#Running the assessments with different settings
aa.xsa <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa)
aa.xsa1 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa1)
aa.xsa2 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa2)
aa.xsa3 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa3)
aa.xsa4 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa4)
aa.xsa5 <- FLXSA(aa.stk, aa.idx, FLXSA.control.aa5)
#Add the results to the stock files
aa.stk <- aa.stk+aa.xsa
aa.stk1 <- aa.stk+aa.xsa1
aa.stk2 <- aa.stk+aa.xsa2
aa.stk3 <- aa.stk+aa.xsa3
aa.stk4 <- aa.stk+aa.xsa4
aa.stk5 <- aa.stk+aa.xsa5
```

```
stocks <- FLStocks(aa.stk,aa.stk1,aa.stk2,aa.stk3,aa.stk4,aa.stk5)

names(stocks)<- c("Shfes0.5","Shfes1.0","Shfes2.0","Shfes1.5","Shfes3.0","Shfes2.5")

plot(stocks)

ggsave("stocks_fse.png",plot(stocks))

###Residuals by fleet (check xsa and Sh)

bubbles(age ~ year|qname, data = index.res(aa.xsa) , main = "Proportion at age by year Shfse0.5")

bubbles(age ~ year|qname, data = index.res(aa.xsa1), main = "Proportion at age by year Shfse1.0")

bubbles(age ~ year|qname, data = index.res(aa.xsa2), main = "Proportion at age by year Shfse2.0")

bubbles(age ~ year|qname, data = index.res(aa.xsa3), main = "Proportion at age by year Shfse3.0")

bubbles(age ~ year|qname, data = index.res(aa.xsa4), main = "Proportion at age by year Shfse4.0")

bubbles(age ~ year|qname, data = index.res(aa.xsa5), main = "Proportion at age by year Shfse2.5")

################ Retrospective analysis###############

library(latticeExtra)

library(np)

################# Results##################

res <- FLQuants("Yield(t)" =landings(aa.stk), "Fbar(0-3)" = fbar(aa.stk), "R(age 1)" = R <- stock.n(aa.stk)[1,,,,], "SSB(t)" = ssb(aa.stk))

res1 <- FLQuants("Yield(t)" =landings(aa.stk1), "Fbar(0-3)" = fbar(aa.stk1), "R(age 1)" = R <- stock.n(aa.stk1)[1,,,,], "SSB(t)" = ssb(aa.stk1))

res2 <- FLQuants("Yield(t)" =landings(aa.stk2), "Fbar(0-3)" = fbar(aa.stk2), "R(age 1)" = R <- stock.n(aa.stk2)[1,,,,], "SSB(t)" = ssb(aa.stk2))

res3 <- FLQuants("Yield(t)" =landings(aa.stk3), "Fbar(0-3)" = fbar(aa.stk3), "R(age 1)" = R <- stock.n(aa.stk3)[1,,,,], "SSB(t)" = ssb(aa.stk3))

res4 <- FLQuants("Yield(t)" =landings(aa.stk4),  "Fbar(0-3)" = fbar(aa.stk4), "R(age 1)" = R <- stock.n(aa.stk4)[1,,,,], "SSB(t)" = ssb(aa.stk4))

res5 <- FLQuants("Yield(t)" =landings(aa.stk5), "Fbar(0-3)" = fbar(aa.stk5), "R(age 1)" = R <- stock.n(aa.stk5)[1,,,,], "SSB(t)" = ssb(aa.stk5))
```

```
#############Diagnostics ################
 (diagnostics(aa.xsa))
(diagnostics(aa.xsa1))
(diagnostics(aa.xsa2))
(diagnostics(aa.xsa3))
(diagnostics(aa.xsa4))
(diagnostics(aa.xsa5))
retro.years <- 2013:2017
aa.stk.retro <- tapply(retro.years,1:length(retro.years),function(x)
  return(window(aa.stk,end=x)+FLXSA(window(aa.stk,end=x),aa.idx, FLXSA.control.aa)))
aa.stk.retro<- FLStocks(aa.stk.retro)
plot(aa.stk.retro)
ggsave("retro.png",plot(aa.stk.retro))
aa.stk.retro1 <- tapply(retro.years,1:length(retro.years),function(x)
  return(window(aa.stk1,end=x)+FLXSA(window(aa.stk1,end=x),aa.idx, FLXSA.control.aa1)))
aa.stk.retro1<- FLStocks(aa.stk.retro1)
plot(aa.stk.retro1)
ggsave("retro1.png",plot(aa.stk.retro1))
aa.stk.retro2 <- tapply(retro.years,1:length(retro.years),function(x)
  return(window(aa.stk2,end=x)+FLXSA(window(aa.stk2,end=x),aa.idx,FLXSA.control.aa2)))
aa.stk.retro2<- FLStocks(aa.stk.retro2)
plot(aa.stk.retro2)
ggsave("retro2.png",plot(aa.stk.retro2))
aa.stk.retro3 <- tapply(retro.years,1:length(retro.years),function(x)
  return(window(aa.stk3,end=x)+FLXSA(window(aa.stk3,end=x),aa.idx,FLXSA.control.aa3)))
aa.stk.retro3<- FLStocks(aa.stk.retro3)
plot(aa.stk.retro3)
ggsave("retro3.png",plot(aa.stk.retro3))
```

```
aa.stk.retro4 <- tapply(retro.years,1:length(retro.years),function(x)
  return(window(aa.stk4,end=x)+FLXSA(window(aa.stk4,end=x),aa.idx,FLXSA.control.aa4)))
aa.stk.retro4<- FLStocks(aa.stk.retro4)
plot(aa.stk.retro4)
ggsave("retro4.png",plot(aa.stk.retro4))
aa.stk.retro5 <- tapply(retro.years,1:length(retro.years),function(x)
  return(window(aa.stk5,end=x)+FLXSA(window(aa.stk5,end=x),aa.idx, FLXSA.control.aa5)))
aa.stk.retro5<- FLStocks(aa.stk.retro5)
plot(aa.stk.retro5)
ggsave("retro5.png",plot(aa.stk.retro5))
#BEST MODEL
save(aa.stk3, file="ARA.xsa3.Rdata")
plot(aa.stk3)
ggsave("stk3.png",plot(aa.st3))
aa.stk3
stock.n(aa.stk3)
harvest(aa.stk3)
#####Consistency of catches and survey indices
my.stock <- aa.stk3
catchn.fli <- FLIndex(FLQuant(NA, dimnames=list(year = dimnames(catch.n(aa.stk3))$year, age =
dimnames(catch.n(aa.stk5))$age)))
index(catchn.fli) <- catch.n(my.stock)
plot(catchn.fli, type="internal")
ggsave("catchnfli.png",plot(catchn.fli, type="internal"))
plot(aa.idx[[1]], type="internal") #survey
ggsave("aaindex.png",plot(aa.idx[[1]], type="internal"))
```

```
####### REFERENCE POINTS ########
CHOSEN_res <- aa.stk3
model = "geomean"
srr <- fmle(as.FLSR(CHOSEN_res, model = model))
spe.brp <- brp(FLBRP(CHOSEN_res, sr = srr))
ref_points<- refpts(spe.brp)
rp_table = data.frame(ref_points@.Data)[,1:5]
temp <- rownames(rp_table)
rp_table = data.frame(rp_table, row.names = NULL)
rp_table <- cbind(temp, rp_table)
colnames(rp_table) =c("", "F","Total Yield","Recruitment","SSB","Biomass")
rp_table_05 <- rp_table[4,]
rp_table

#####FORECASTING
load("ARA.xsa3.Rdata")
my.stock<-aa.stk3
year <- c(range(my.stock)["minyear"]:range(my.stock)["maxyear"])
age <- c(range(my.stock)["min"]:range(my.stock)["max"])
#Taking a look to the rec and the SSB
rec(my.stock)
ssb(my.stock)
plot(rec(my.stock),xlab="year",ylab="R")
plot(ssb(my.stock),xlab="year",ylab="SSB")
plot(ssb(my.stock),rec(my.stock),xlab="SSB",ylab="R",main="MUT SSB and R")
ggplot(data = FLQuants(Yield = catch(my.stock),ssb=ssb(my.stock),rec(my.stock),aes(year,data)
                + geom_line() +facet_wrap(~qname,scales ="free", nrow =3)))
# We can convert a FLStock into an FLSR
```

```
my.stock.sr <- as.FLSR(my.stock)

summary(my.stock.sr)

# To fit the stock-recruitment model, we need to select a functional form

########################################### RICKER

model(my.stock.sr) <- ricker()

model(my.stock.sr)      #We can see here the formula of Ricker

# Fitting by MLE

my.stock.sr_R <- fmle(my.stock.sr)

summary(my.stock.sr_R)

plot(my.stock.sr_R)

ggsave("ricker.png",plot(my.stock.sr_R))

AIC(my.stock.sr_R)

########################################### BEVERTON & HOLT

model(my.stock.sr) <- bevholt()

model(my.stock.sr)      #We can see here the formula of Ricker

# Fitting by MLE

my.stock.sr_BH <- fmle(my.stock.sr)

summary(my.stock.sr_BH)

plot(my.stock.sr_BH)

ggsave("BevHolt.png",plot(my.stock.sr_BH))

AIC(my.stock.sr_BH)

################SHORT TERM PROJECTION ###################

# Projection to 3 years using FLAsh

# We are going to project 3 years using the mean of the last 3 years for the parameters: weights,
selectivity, M, ogive

my.stock_stf <- stf(my.stock , nyears=3 , wts.nyears=3, na.rm=TRUE)

plot(my.stock_stf)

ggsave("projection.png",plot(my.stock_stf))

#We are going to set the Rec as the geometric mean of the last three years rec.

#For that, we create a new model:
```

```
rec_mean <- exp(mean(log(rec(my.stock[,(length(year)-2):length(year),,,,]))))     #geometric mean rec last three years

my.stock.sr <- as.FLSR(my.stock, model="geomean")

params(my.stock.sr)['a',] <- rec_mean

params(my.stock.sr)

my.stock.sr_best <- my.stock.sr   #We change our best SR in order to have the mean

############################################ First, we make a projection with Fsq

year_proj <- c((year[length(year)]+1):(year[length(year)]+3))

ctrl_target <- data.frame(year = year_proj, quantity = "f", val = fbar_SQ)

ctrl_f <- fwdControl(ctrl_target)

ctrl_f

my.stock_sq <- fwd(my.stock_stf, ctrl = ctrl_f, sr = my.stock.sr_best)

plot(my.stock_sq)

ggsave("my.stock_sq.png",plot(my.stock_sq))

############################################ Making a projection with Fmsy

ctrl_target <- data.frame(year=year_proj,quantity= "f", val = as.numeric(refpts(my.stock.BRP)[2,1]))

ctrl_f <- fwdControl(ctrl_target)

ctrl_f

my.stock_msy <- fwd(my.stock_stf, ctrl = ctrl_f, sr = my.stock.sr_best)

plot(my.stock_msy)

ggsave("my.stock_msy.png",plot(my.stock_msy))

############################################ Making a projection with F0.1

ctrl_target <- data.frame(year=year_proj,quantity= "f", val = as.numeric(refpts(my.stock.BRP)[4,1]))

ctrl_f <- fwdControl(ctrl_target)

ctrl_f

my.stock_01 <- fwd(my.stock_stf, ctrl = ctrl_f, sr = my.stock.sr_best)

plot(my.stock_01)

ggsave("my.stock_f01.png",plot(my.stock_01))
```

```
########################################## Making a projection with F=0
ctrl_target <- data.frame(year = year_proj, quantity = "f", val = 0)
ctrl_f <- fwdControl(ctrl_target)
ctrl_f
my.stock_0 <- fwd(my.stock_stf, ctrl = ctrl_f, sr = my.stock.sr_best)
plot(my.stock_0)
ggsave("my.stock_f0.png",plot(my.stock_0))
########################################## Making a projection with F30%
ctrl_target <- data.frame(year=year_proj,quantity= "f", val = as.numeric(refpts(my.stock.BRP)[6,1]))
ctrl_f <- fwdControl(ctrl_target)
ctrl_f
my.stock_30 <- fwd(my.stock_stf, ctrl = ctrl_f, sr = my.stock.sr_best)
plot(my.stock_30)
ggsave("my.stock_30%.png",plot(my.stock_30))
##################ALL PROJECTIONS
stocks_stf <- FLStocks(my.stock_sq , my.stock_msy, my.stock_01,my.stock_0,my.stock_30)
names(stocks_stf)<- c("FSQ","FMSY","F0.1","F0","F30%")
plot(stocks_stf)
ggsave("projectionstocks_stf.png",plot(stocks_stf))
```

Universitat d'Alacant
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GOBIERNO DE ESPAÑA

MINISTERIO DE AGRICULTURA, PESCA Y ALIMENTACIÓN

CIHEAM

El Máster Internacional en GESTIÓN PESQUERA SOSTENIBLE está organizado conjuntamente por la Universidad de Alicante (UA), el Centro Internacional de Altos Estudios Agronómicos Mediterráneos (CIHEAM) a través del Instituto Agronómico Mediterráneo de Zaragoza (IAMZ), el Ministerio de Agricultura, Pesca y Alimentación (MAPA) a través de la Secretaría General de Pesca (SGP).

El Máster se desarrolla a tiempo completo en dos años académicos. Tras completar el primer año (programa basado en clases lectivas, prácticas, trabajos tutorados, seminarios abiertos y visitas técnicas), durante la segunda parte los participantes dedican 10 meses a la iniciación a la investigación o a la actividad profesional realizando un trabajo de investigación original a través de la elaboración de la Tesis Master of Science. El presente manuscrito es el resultado de uno de estos trabajos y ha sido aprobado en lectura pública ante un jurado de calificación.

The International Master in SUSTAINABLE FISHERIES MANAGEMENT is jointly organized by the University of Alicante (UA), the International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM) through the Mediterranean Agronomic Institute of Zaragoza (IAMZ), and by the Spanish Ministry of Agriculture, Fisheries and Food (MAPA) through the General Secretariat of Fisheries (SGP).

The Master is developed over two academic years. Upon completion of the first year (a programme based on lectures, practicals, supervised work, seminars and technical visits), during the second part the participants devote a period of 10 months to initiation to research or to professional activities conducting an original research work through the elaboration of the Master Thesis. The present manuscript is the result of one of these works and has been defended before an examination board.